Universidade de Aveiro
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Departamento de Economia, Gestão, Engenharia Industrial e Turismo

João Miguel de Oliveira Esteves Correia

Lean aplicado na gestão da produção de protótipos - Proposta de um modelo

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Projeto apresentado à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia e Gestão Industrial, realizada sob a orientação científica do Professor Doutor Luís Miguel Domingues Fernandes Ferreira, Professor Auxiliar, do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro.

Dedico este trabalho a um grande amigo, Manuel Pires de Oliveira.

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palavras-chave

Prototype Production Management, PDDIS framework, Lean Management, Lean Office

resumo

Com o aumento da concorrência nos mercados globais, um aumento na necessidade de criar produtos de maior qualidade está presente nas empresas. Para manter e melhorar a quota de mercado, as empresas devem produzir produtos de alta qualidade a baixo custo e torná-los disponíveis no mercado dentro do menor tempo possível. A fim de assegurar que apenas os melhores produtos estão presentes no mercado, protótipos devem ser construídos e testados, iterações e correções devem ser feitas. No entanto, o processo de criação de protótipos viáveis requer um fluxo de valor de produção não-padrão, de modo a abraçar a criatividade aberta, usando processos produtivos com um foco não na otimização da produção, mas capazes de alcançar uma vasta gama de transformações no produto, onde cada operação pode ser única. Esta tese apresenta uma proposta de modelo de Lean Prototype Production Management, que descreve os resultados numa organização industrial, fornecendo uma melhor compreensão de como a aplicação dos conceitos de Lean Thinking tem impacto no processo de gestão de produção de protótipos.

keywords

Prototype Production Management, PDDIS framework, Lean Management, Lean Office

abstract

With the increase of international competition in global markets, a strive for higher quality goods is present in the companies. To sustain and improve market share, companies must produce high quality products in a low-cost perspective and make them available in the market within the shortest time possible. In order to assure that only the best products go to the market, prototypes must be built and tested, iterations and corrections must be made. However, the ability to create feasible prototypes requires a non-standard manufacturing value stream, in order to embrace open creativity, using processes without a focus on the production optimization, but capable of achieving a wide range of product transformations, where each operation might be unique. This thesis presents a proposal of a new Lean Prototype Production Management framework, which outlines results in a manufacturing company, providing better understanding on how Lean Thinking application impacts prototype production management.

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1. Introduction

1.1. Aim and Motivation

The today's business environment is characterized by the rising product variety and demands of customers for lower prices, higher product quality, and shorter lead times (Dombrowski & Zahn, 2011). Specially in the development processes, more and more enterprises are beginning to develop holistic concepts to improve efficiency ("Doing the right things") (Martin & Osterling, 2007), effective-ness ("Doing the things right"), and to increase the capabilities of the employees and the organization (Sassanelli et al, 2015; Chiarini, 2013). The maximization of value creation through better efficiency, performance rates and good practices took the place of the great investments in resources and technology. However, new engineering products continue to under-perform in their lead times, cost and quality.

Lean Thinking is a philosophy known for its good results across the manufacturing industry, widespread among such organizations as Ford, Boeing, Dell and Toyota (Bhuiyan & Baghel, 2005; Chen & Cox, 2012). The philosophy itself is mostly present in the manufacturing companies, but can be applied with great results outside this area, to management and administration units, although the examples of this 'white collar' applications are still relatively rare (Baines et al, 2006). Up to now, bottleneck management research has concentrated on manufacturing processes, while neglecting product design and engineering processes (Hinckeldeyn et al, 2014). There has been comparatively less research done to apply 'lean' to product and process development: the design process, from the concept stage to the detailed development of products and their related manufacturing processes (Khan et al, 2013). Waste is more visible in the manufacturing process, but there is little doubt that the management and administration sectors have room to improve in competitiveness and efficiency though the application of Lean principles (Chen & Cox, 2012).

While most wastes are visible and easily quantifiable in a manufacturing environment, they are more difficult to be distinguished and measured in an office environment (Chen & Cox, 2012). Could this mean that the management and service support areas to the manufacturing are also affected by the waste they wanted to eliminate from the manufacturing areas, and by this, become the new bottleneck of the companies' value chain?

Do more with less. Not only at an enterprise level, but also at a global level, our society is becoming more aware of the need to save resources, cutting costs, being sustainable. Lean Thinking is a result of this necessity (Womack and Jones, 1996). The concept of lean thinking was born in the late 1980s, from the studies of the Japanese automotive industry inspired by Toyota, whom acted as a role model and implemented this philosophy in the manufacturing areas of the company. Lean Thinking has its most common application in the direct areas, where the manufacturing takes place. It is easier to measure the waste in these areas, and therefore, to eliminate it. While this waste removal can decrease production lead times with easily measurable results, these isolated successes within a manufacturing company are not sufficient to ensure long time survival in today's economy. What is needed is a new paradigm that will take lean thinking concepts from waste elimination into value creation. In order to make a significant change in enterprise performance and saving ultimate system costs, there is a need for the entire enterprise to undergo a lean transformation (Al-Ashaab and Sobek II, 2013), and not only the manufacturing areas.

This thesis focuses on the prototype production area in the technical department, which aids the research and development (R&D), and is responsible for creating prototype samples to be validated during the test phase of new products. The process to create a prototype will be studied, from the moment the request to initiate production is submitted, until the moment of delivery, with a focus to eliminate waste activities, increasing the value added ones.

The aim of this thesis is to formulate and propose a new Lean Management framework, possible to be adapted to any management scenario, with a focus on indirect areas. With this approach, a better understanding of how the lean implementation without a focus on manufacturing but on management can affect the efficiency of a production area. To structure the information and work accomplished, the document is divided in 5 chapters:

- Chapter 1: The present one, where information about the problem is presented, as well as the methodology to solve it and the objectives to reach.

- Chapter 2: An overview on the theoretical framework regarding the subject will be provided. The focus on the Lean Thinking principles and methodologies, their evolution and applicability to management areas, formulating the framework of Lean Management (LM).

- Chapter 3: In this chapter, the research aims and methodology will be explained, as well as the research process. A case study company is selected in order to establish the company's initial state.

- Chapter 4: The Lean Management Framework is proposed, based on the results of its application in the case study company.

- Chapter 5: This chapter will be dedicated to the conclusion of the thesis. The contribution of the new Lean Management framework will be argued, addressing the research questions as well as the management implications. Also, suggestions for further studies on this subject will be present.

2. Literature Review

The lean thinking focus has been the improvement of the manufacturing process, although it has been a subject of research for nearly two decades. (Khan et al, 2013). According to George Gonzalez-Rivas, 2010, the three Lean areas are:

The 3 Lean Areas	Definition	Visibility
Factory Lean	Classic Lean Characterized by the material flow and reverse metaflow information	Highly visible
Paper Office Lean	The white collar analog to Factory Lean. Characterized by material flow (in the form of documents, mostly paper but partly electronic)	Mostly visible
Information Office Lean	No material whatsoever flows; documents are primarily electronic and can be printed if needed.	Mostly visible

Table 1 - The 3 Lean Areas
Source: Gonzalez-Rivas (2010)

The aim of the research is to investigate the impact of the application of Lean Thinking in the management process, collecting information about existing Lean models applicable to the management area, as well as resulting benefits and challenges. Therefore, in order to embrace the collection of articles that serve as theoretical framework, some conditions were defined:

- To guarantee accordance with the focus of the thesis subject, only articles published in the fields of Business Management, Engineering and Social and Physical Sciences were selected. The articles were searched and analyzed using the academic databases Scopus and Science Direct.
- Due to a lack of existing literature related specifically to Lean Management or Lean implementation in indirect areas, a wider spectrum of keywords was used. Those were "Lean Management", "White Collar Lean", "Lean Office" and "Lean Product Development".
- Only literature published after 2000 was adopted. This option to restrict the research to a more recent background was due also to the lack of existing literature related to Lean Management.

The literature regarding Lean Management has been reviewed, allowing a better understanding about the evolution from Lean Manufacturing, applied mainly in direct areas, to Lean

Management, applied in white collar, indirect areas, as well as literature regarding management performance.

2.1. Lean Thinking

Henry Ford systemized lean manufacturing during the early nineteenth century when he established the concept of mass production in his factories. This methodology is a systematic approach to identifying and eliminating waste through continuous improvement by following the product at the pull of the customer in pursuit of perfection (Baghel, 2005). Learning a great deal from Henry Ford's assembly lines, and customizing a production process to suit the needs of the Japanese markets, which called for lower volumes of cars, Taiichi Ohno pioneered and developed the world renowned Toyota production system (TPS), also known as lean manufacturing and now used throughout the world (Womack et al., 1990). The TPS is the foundation for what has become a Lean Thinking global movement, being represented as a house. A house is only strong as its weakest part. With a weak foundation or pillar, the house will not be stable, meaning the system can "crumble" on itself. All the parts must work together as a whole.

Figure 1 - The Toyota Production System (TPS) house
Source: Liker and Morgan (2006)

Taiichi Ohno was the first person to recognize the enormous amount of *Muda* that exists in the *Gemba*, as well as recognizing that only a small portion of the daily activities can be really considered as value. The resources at each process (people and machines), either do or do not add value. *Muda* refers to waste, any activity that does not add value. Ohno classified *muda* in the *Gemba* according to the following seven categories (Imai, 2012), which are:

- **Overproduction** - Producing items for which there are no orders, which generates such wastes as overstaffing and storage and transportation costs because of excess inventory.
- **Waiting (time on hand)** - Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, part, etc., or just plain having no work because of stock outs, lot processing delays, equipment downtime, and capacity bottlenecks.
- **Unnecessary transport** or **conveyance** - Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes.
- **Over processing** or **incorrect processing** - Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary.
- **Excess inventory** - Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
- **Unnecessary movement** - Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc. Also, walking is waste.
- **Defects** - Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort.

Womack and Jones state that Lean Thinking is antidote to *muda*. It provides a way to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively.
In short, Lean Thinking is lean because it provides a way to do more with less - less human effort, less equipment, less time, and less space - while coming closer to providing customers with exactly what they want (Womack and Jones, 1996), as represented in Fig. 2.

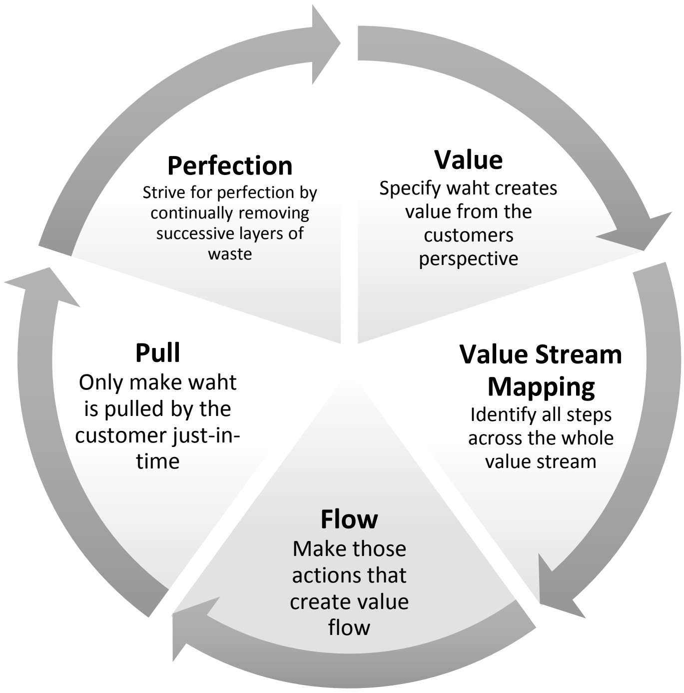

Figure 2 – The 5 Lean Thinking Principles
Source: Womack and Jones (1996)

Although waste is more visible in factories, there is no doubt that the application of Lean principles in the services sector represents an opportunity for improvements in competitiveness (Baines et al, 2006). It is claimed by Womack (1996) and others that 'Lean thinking' can be applied to great effect outside manufacturing operations, although examples of this such as applications in service-based enterprises are relatively rare (Baines et al, 2006).
Companies perceived the importance of ensuring an optimal transformation to a lean environment, across all areas and departments. Nowadays, this philosophy is spread among a diverse range of enterprises, including services, like insurance, banking and healthcare.
In order to understand how to better implement such philosophy, a deep knowledge of the area in focus must exist, including deliverables and processes present.

2.2. Prototype Development Process

Organizational survival and long-term growth increasingly depend upon the introduction and development of new products (Al-shaab and Sobek II, 2013). It is fundamental to first comprehend the stages of the Product Development Process, depicted in Fig. 3, in order to understand the pivotal importance of the prototype production.

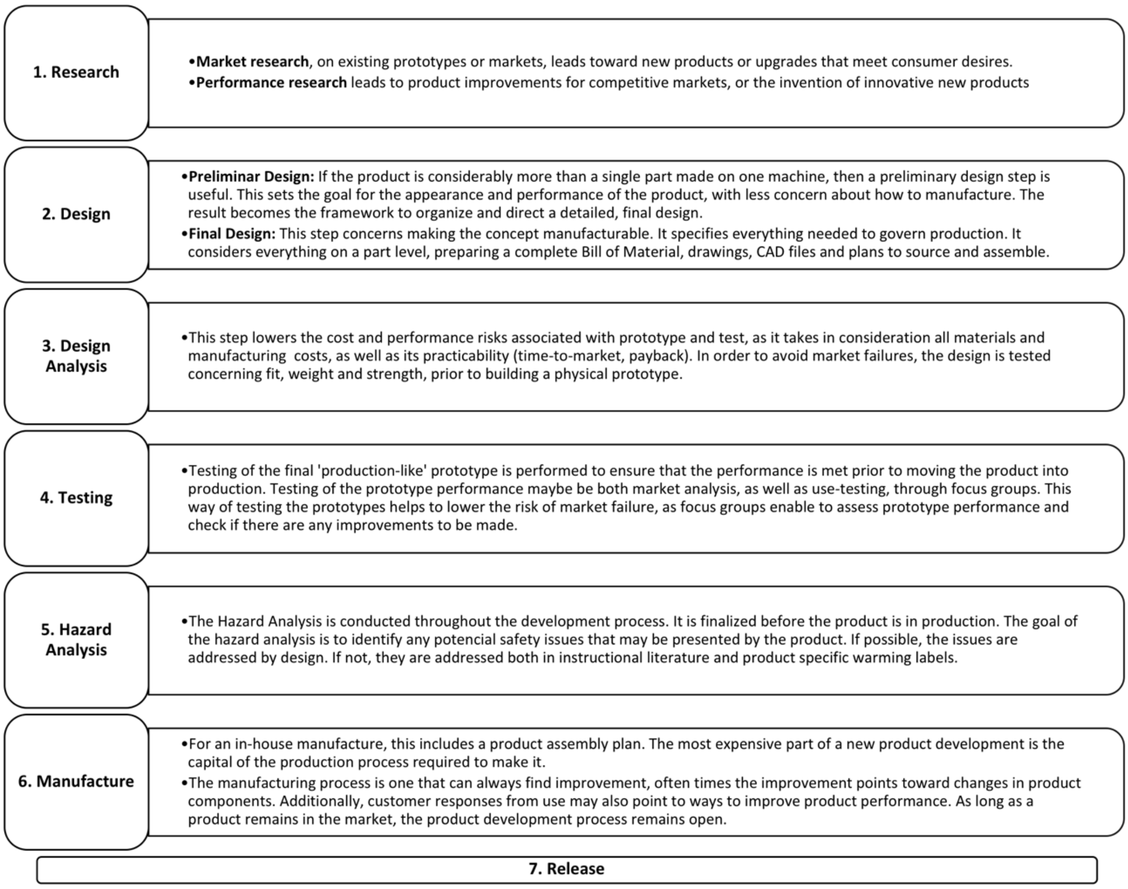

Figure 3 - Product Development Process

The analysis is performed on a design prior to prototyping and testing. With the analysis concluded, the specifications of materials to use and dimensions are confirmed. The request with all the information need is made to the prototyping team, which analyses the prototype information and determines the next steps, planning the necessary workload and needed material. After the prototype production is concluded, the necessary tests are made (Fig. 4).

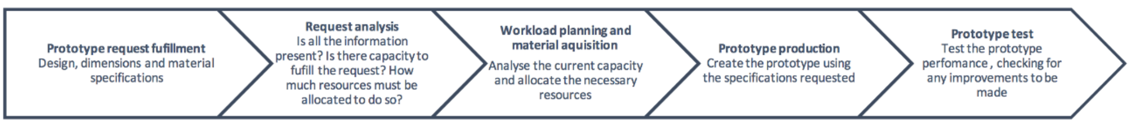

Figure 4 - Prototype Development Process

The prototype development process can be considered as one of the core processes of a company, responsible for sustaining and improving market share by being able to produce high-quality and innovative products in a cost-effective manner in a shorter time (Al-Ashaab and Sobek II, 2013). With the service as the strategic plan for competitive advantages, manufacturing companies will compete not only in the product they provide but also in the service that they can provide for their customers (Sabur & Simatupang, 2015).

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In order to achieve customer satisfaction, every company will strive hard to improve its business process to meet the customer needs (Sabur & Simatupang, 2015). In recent years, manufacturing organizations have recognized that service superiority is a principal strategic device to gain competitive advantages (Jaaron and Backhouse, 2011). Customers can be won or lost due to administrative processes that go along with services transactions, and it is imperative that costs are maintained (or reduced) with the same level of service (Bonaccorsi et al., 2011). With service as the strategic plan for competitive advantages, manufacturing companies will compete not only in the product they provide but also in the service that they can provide for their customers. Therefore, it is important that manufacturing companies also improve their service dimension.

2.3. Lean Management Applications & Models

One of the key phases in Lean is the identification of non-value added steps in order to streamline a process. By classifying the steps of a processes into two categories, value added and non-value added, it is possible to initiate actions to improve the former and eliminate the latter by reducing wastes in both of them.

Transportation waste in manufacturing, for example, can be measured by estimating the time consumed while moving work in process (WIP) from one workstation to next workstation. On the other hand, in an office environment, most of the tasks are translated via email or fax, causing more variation in time consumption, and correct arrive and departure times are difficult to determine. Inventory waste in manufacturing can be classified by calculating the WIP level in the workstation or finished goods in the warehouse, but it is hard to identify the amount of pending items in each office job. Moreover, time waste due to waiting can be evaluated by accumulating the total idle time of machines or operators; whereas, the idle time in the office is difficult to judge because some tasks require confirmation by a supervisor or customer. This makes it difficult to assess the problem due to lack of definition of office workers' idle time. Furthermore, the defect rate can be measured by calculating the amount of finished product and WIP that fail inspection divided by the amount of parts that pass inspection, but it is hard to establish a measurement in an office environment to distinguish whether the task is failed or not because there are many variables in these tasks (Chen & Cox, 2012). Not only are office wastes difficult to define, lack of references about conducting Lean in an office environment leave participants struggling in how to get started (Corrie, 2004). Although some Lean Office projects have been documented, a systematic procedure for creating a Lean Office has not been universal (Tonkin, 2004).

Although, various researches have been performed regarding the application of Lean production principles into the service sector:

- Cuatrecasas (2004) proposed the implementation of a Lean Management method in service operations, including a system for calculating the main magnitudes of the operation efficiency and optimization;
- Ahlstrom (2004) also translated Lean production principles into the service sector, and concluded that Lean production is applicable to service operations with some contingencies to the application that stems from the characteristics of services;
- Piercy & Rich (2009) applied Lean's improvement tools for improving the quality of service delivery within a pure service environment and concluded that Lean could give high quality with low cost in the service sector;
- Bonaccorsi et al. (2011) employed Lean concepts, especially tailored VSM to the specific requirements of pure services by making some adaptations to the VSM method, from which new icons for a detailed process map are created, Lean approaches have been modified and both takt-time and pitch concept have been redefined into a more suitable way;
- Kalbach & Khan (2011), in terms of locating the value in the flow, proposed to use a service blue print, alignment diagrams, a mental model and a journey map in locating the value of a service system;
- Portioli-Staudacher & Tantardini (2012) investigated the main problems in implementing Lean in supply chains of service companies and defined the characteristics of Lean in service companies;
- Psychogios et al. (2012) applied Lean Six Sigma in the telecommunication industry, which resulted in an integrated framework for the effective implementation;
- Balazin and Stefanic (2013) carried out research for applying Lean concept into a consultant company that studied environmental impact and concluded that Lean can be a successful approach for the processing complex services.

The above-mentioned researches present an example of the LM applications on the service sector, without a specific focus on the service support to the manufacturing sector (Renna, 2012). Even though the lean thinking application in the administration and office areas is taking its first 'baby steps', some scholars have proposed Lean Management Models that go beyond lean manufacturing, in an attempt to ensure a lean manufacturing support service, transposing the enterprise culture to a lean environment:

- Jaaron & Backhouse (2011) focused their research on service as a principal strategic device through which to gain competitive advantage, on developing a methodology for implementing Lean thinking into the manufacturing support services and on developing alternative implementation recommendations;
- Chen & Cox (2012) proposed a systematic procedure for conducting Lean Office techniques, in which Lean principles were implemented into a local company's office environment.

In order to understand the models proposed in the researches above-mentioned, a deeper analysis is, therefore, mandatory, generating the creation of background awareness.

Chen & Cox (2012): 'Value Stream Management for Lean Office—A Case Study'

According to Chen & Cox, (2012), it can be more difficult to bring the concept of Lean into the office environment than a manufacturing area because of a lack of understanding, a lack of cooperation between departments, and a lack of directive from the top management. The proposed procedures for providing a systematic approach for implementing Lean in an office environment consist of the following six steps:

I. <u>Form a Lean event team and provide Lean training to team members</u>

Before conducting a Lean event, some preparations should be made, and a Lean event team must be formed:

- It must be shown to the office administrators some typical cases of how lean is successfully implemented in a manufacturing environment.
- The blueprint must be described, after implementing lean office to convince the office managers it is cost-effective.
- The selection of team members depends on the goal of this event or targeted department which is considered as a bottleneck in the company.

The basic rule for selecting members is to find major processes that are related to this Lean event and separate these into individual process. Then, determine the owner of each process related to this event for providing necessary information; moreover, fundamental training of team members is necessary to create a common language among the team members and to help sustain the Lean event in the company.

Lean philosophies are also described as a building with component blocks, which is shown in Figure 5. As seen in this figure, there are several Lean principles that can be used to eliminate waste from the system. Descriptions of these Lean principles are listed in Table 2. Once the basic Lean concepts have been introduced to team members, they will have a better sense about how to use these principles to eliminate waste and add value to the product.

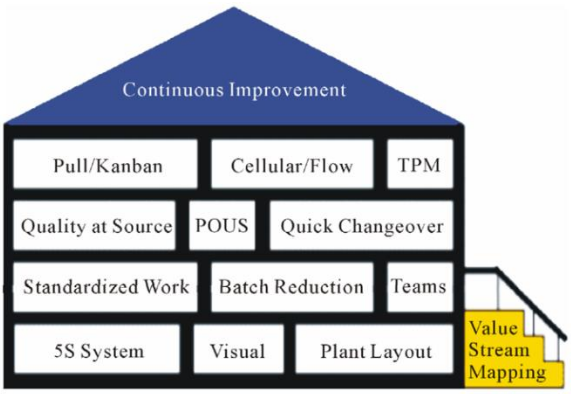


Figure 5 - Lean Building Blocks (Chen & Cox, 2012)

In the Figure 5, it can be seen the important step to lead the team into the rest of the Lean building blocks is Value Stream Mapping (VSM). VSM is one of the most powerful Lean tools available (Wan & Chen, 2007). It combines material production flows with information flows of company in a map; moreover, it forms the basis of implementation plan for company to start its Lean journey (Rother & Shook, 2003). By mapping the whole processes, team members are able to visualize more than the single-process level and realize the connection between information flow and material flow. The four steps that follow summarize the process for creating an office value steam map.

Lean Principles	Description
Standardized Work:	Reducing the amount of variation in both the process and output with work instructions.
Quality at Source:	The product or information which will be passed to the next station should be confirmed as acceptable quality. Templates and samples can be used as tools to efficiently perform the inspection.
5S or Workplace Organization:	An organized work place helps workers perform their task efficiently and provides a specific location for everything required. These 5S' are described in the following: 1) Sort: What is not needed should be sorted out from the working place. 2) Set-in-order: Make what must be kept, visible and easily distinguishable. 3) Shine: The work place and equipment should be cleaned periodically. 4) Standardize: Make a standard for above three S's". 5) Sustain: These rules should be followed by every worker in the station.
Point of Use Storage (POUS):	Raw material is stored at the work station where it is used. Visual tools such as cards and record boards can be used as a tool to simplify inventory tracking, storage, and handling.
Visual Control:	Simple signals such as cards, lights, color-coded tools, and lines delineating work are used as tools to provide immediate information in the working place.
Team:	Lean philosophy values teamwork; therefore, any improvement suggestion in the company should be discussed among team members and provided to supervisory level manager.
Batch Size Reduction:	By reducing the batch size, the lead time of completing a service or production will be reduced and quickly satisfying the customer demand also help company to have a better cash flow.
Pull System:	A pull system is a flexible and simple method of controlling and balancing the flow of resources. Production and service is based on customer demand rather than forecasting.
Work Cells:	Creating a cellular design rather than in a traditional straight line that will provide a better utilization of people and communication.

Table 2 - Basic Lean principles and description (Chen & Cox, 2012)

II. Selecting a product/service family for conducting VSM

Customers care about their specific products, not all available products (Rother & Shook, 2003). Therefore, it is important to identify and focus on a single family of products from the customer end of the value stream. It is only necessary to map things that are relevant to this product or service, as selected by the team leader, because drawing everything that happens in the plant on one map would make the map too complicated (Rother & Shook, 2003). Products or services which involve similar customers and similar supplier inputs should be put together as a target product family and drawn on one VSM. That makes the VSM easier to visualize and understand.

III. Drawing the current-state map

A current-state map value stream map is a tool that helps teams see and understand the present flow of material and information. There are several tips for drawing a current-state map (Rother & Shook, 2003). The first tip is that the map should be drawn by hand in pencil; drawing by hand can be done without delay and helps members focus on the flow rather than how to use computer software. The second tip is to collect current-state information while "walking through" the actual pathway of the material and information flow. Remember, mapping cannot be done in a conference room; members should physically go see and understand how each task is really done. Furthermore, the process owners can provide any information to team members with as much detail as possible. The third tip is that members should start at the customer end and work upstream because services or products should be driven by customer demand. Therefore, the process that is linked most directly to the customer should be considered as the beginning and the pace for other processes further upstream. Following these tips, members can bring a stopwatch, paper and pencil and then start to draw the current map. Typically, it takes five steps for drawing an office value stream map (Rother & Shook, 2003):

1) Document customer information and needs;
2) Perform a value stream walk-through for identifying processes, filling data boxes, and calculating WIP numbers;
3) Show the linkage of information flow and material flow in the office;
4) Calculate lead time and process times;
5) Complete the current-state map with lead time bars and data.

Although the mapping process might be labor intensive, it takes the team to a deeper level of understanding of what is actually happening and makes the case for change more compelling. Additionally, the current-state map provides foundational information for the future state. After creating the current map all of the team members are able understand the entire process, and to have more information for brainstorming the future state of the company.

IV. Brainstorming and developing a future-state map

The future state should be a chain of processes, where each individual process is linked to their internal and external customers, streamlined so that each process should only produce what its customer needs, when they need it (Rother & Shook, 2003). In this step, team members should go through the following seven questions and mark the future state ideas directly on the current-state map based on the answers to these questions.

1) What/When does the customer need?
2) How often will we check our performance to customer needs?
3) Which steps create value and which are wastes?
4) How can we flow work with fewer interruptions?
5) How do we control work between interruptions? How will work be prioritized?
6) Is there an opportunity to balance the workload and/ or different activities?
7) What process improvements will be necessary?

Once the team has brainstormed ideas for the future state as described above, a future value stream map can be drawn. Rother & Shook described the purpose of VSM as: "to highlight sources of waste and eliminate them by implementation of a future state value stream that can become a reality within a short period of time". After proposing a future value stream map, the team members should start to think about how to make the future state become a reality as soon as possible.

V. Proposing a value stream plan to reach the future stage of VSM

Future value stream maps demonstrate an ideal state for companies. It is essential to make a plan for achieving the future state; otherwise the future value stream map will become worthless. A yearly value stream plan should be created. A value stream plan includes the implementation plan from the current state to the proposed future state. This plan consists of several loops separated from entire office processes, such as research and development, finance, and customer service (Rother & Shook, 2003). In most cases it will not be possible to achieve the future state all at once because the proposed future value stream map demonstrates the entire flow through the office. Therefore, dividing the proposed future state map into several loops and improving individual loops is easier for team members to implement (Rother & Shook, 2003). The four steps that are used when improving an individual loop are:

1) Develop a streamlined process that operates based on customer demand;
2) Establish a pull system to control production;
3) Apply leveling;
4) Practice Kaizen to continually eliminate waste and extend the range of streamlined processes.

There are several points that should be indicated in the value-stream plan, such as what will be implemented in an individual loop, how to do that and when, measurable goals, a clear check point with real deadlines, and an assigned reviewer.

VI. Conducting kaizen events for distinguishing and eliminating wastes

Kaizen is a Japanese word that translates to "continuous improvement". In the office environment, Kaizen focuses primarily on the improvement of an individual loop through the efforts of process owners by using their experience (Lareau, 2002).

Normally, there are three steps to perform the Kaizen activity which are:

1) Utilize the 5 why's method to find the root cause of wastes (Womack & Jones, 2003), using the following guidelines:
   a) Writing down the problem helps you formalize the problem and describe it completely. It also helps a team focus on the same problem;
   b) Ask why the problem happens and write the answer down below the problem;
   c) If the provided answer doesn't identify the root cause of the problem that you wrote in step 1, ask why again and write that answer down;
   d) Repeat above steps until the team is in agreement that the problem's root cause has been identified.
2) Brainstorm and develop the resolution to meet the goal;

3) Implement resolution and sustain.

The application of Lean principles in a manufacturing area means identifying the value added and non-value added activities in manufacturing processes and then eliminating the non-value added activities while improving the value added activities. The systematic procedure proposed here extends this concept to transform an office environment into a Lean office that has customer-triggered working processes, faster, more efficient and systematic task tracking, and reduced costs due to a reduction of non-value added activities.

Jaaron & Backhouse (2011): 'A methodology for the implementation of lean thinking in manufacturing support services'

According to Jaaron & Backhouse, (2011), an organization's competitors, equipped with the latest technology, are able to produce physical products with almost the same high quality. This has resulted in many organizations adopting new innovative ways to distinguish themselves from their competitors and to achieve competitive success not through the products they produce, but through the services they provide (Gebauer, 2007; 2009). Therefore, several manufacturing firms have become more service-oriented through the development of competition strategies based on service customization and innovation (Rajagopal, 2009; Bryson, 2010). As a result, change in service operations management has become one area where the fierce competition battle can be won (Song et al., 2009).
Lean thinking is a service operations model that can help the management analyze customer demand (Jackson, 2008) to achieve the benefits presented above. The office processes transformation on the basis of lean thinking service design requires five different stages developed by Seddon (2003, 2008), these stages are presented below:

I. <u>Check</u>

At this stage customer demand is analyzed over a period of time to identify the main demands. Demand is analyzed on the basis of value and failure demand. The demand analysis strategy forms the basis for increasing the service capacity by identifying the reasons that hampered customer demand fulfilment in some demand areas. However, the need to satisfy customer demands and reduce the frequency of failures requires the elimination of waste in the service systems and the redesign of service operations to absorb variety. This will reduce resource consumption and improve capacity (Seddon, 2005).

II. Redesign

This stage involves redesigning the processes flow taking into account what has been learnt in relation to the customer ‘wants’ and then mapping out the new service system design. Process flow diagrams are created for every service operation; all processes classified as waste are marked in red on the process flow diagram. Processes that add value from a customer’s point of view are marked in green. The minimization of waste in service operations requires the redesign of service operations flow in such a way that the non-value adding activities are minimized in order to deliver solutions in minimal time (Busi, 2005; Christopher, 2000). However, this can only be done by designing operations from the customer point of view.

III. Experiment

The new service design is used in an experimental environment with the aim of testing, re-designing and re-testing new processes to make sure that customers get the best possible service. It is anticipated that new service operations significantly reduce service delivery delay and bring productivity improvement in the processing of customer demands and enquiries.

IV. Roll-in

A gradual rolling in of employees to the new way of working is progressed at this stage. It is key at this stage to continue the identification of appropriate training needs of employees. This training includes learning about lean thinking, putting it into practice and understanding and using the new ways of working as designed at Stage 2.

V. Continuous Improvement

This stage is embedded into the fully operational environment and involves making smaller changes to the way of working to improve the service offered. It also involves the identification of new demands coming in, the designing new processes that ensure new demands are treated as value demands.

Lean thinking requires the decision-making processes to be at the employee’s level to make sure that the waste is avoided and that employees are able to deliver the service with minimal consumption of resources (Seddon, 2005). Therefore, lean thinking is considered as the service delivery design with maximum economy; it gives customers only what they want in minimal time of interaction (Seddon and Brand, 2008). In this approach employees are given freedom to act and their roles change so does their job experience.

The advent of lean thinking requires that managers change the way they think about their systems. Instead of exerting control on employees to follow work standards and monitoring their performance, it is required that attention focuses on the design and management of the systems itself (Seddon, 2003). This is because more than 95% of performance variations are in the system, and only 5% or less are in the employees (Deming, 1993). However, in order to enable working on the 95% of system variation employees need to be actively involved in this process. Lean thinking requires the decision-making processes to be at the employee's level to make sure that the waste is avoided and that employees are able to deliver the service with minimal consumption of resources (Seddon, 2005). Therefore, lean thinking is considered as the service delivery design with maximum economy; it gives customers only what they want in minimal time of interaction (Seddon and Brand, 2008). In this approach employees are given freedom to act and their roles change so does their job experience. Collective team work and responsibility sharing is of great importance in order to identify the right person or persons to solve a demand problem at minimal time, therefore increasing the process performance.

2.4. Lean Manufacturing vs Lean Management

Nowadays, regardless of the origin, the value of the Lean paradigm (focus on activities that are of service to the customer and, whenever possible, reduce waste of materials, time and motion) to the success of manufacturing is now unquestionable (Baines et al, 2006).

Although the implementation of Lean principles in the manufacturing area may bring short term results since the value added activities are being directly affected, the implementation on indirect areas, whom are also a vital part of the process, can bring positive results, even in a long term perspective. In order to differentiate both paradigms, Table 3 represents a summary of Lean Manufacturing and Lean Management differences.

Topic	**Lean Manufacturing**	**Lean Management**
Implementation in companies	Spread among companies around the world	Lean Management is now taking the first "baby steps", without some outside research applications
People	Low qualified people (workforce)	High qualified people (managers and engineers)
Variability	Must be eliminated in the manufacturing process, because it leads to deviation and quality issues.	Unplanned activities must be reduced to a minimum.
Area of application	Direct areas (repetitive processes)	Indirect areas (non-repetitive processes)
Standardization	Manufacturing processes must be repeated exhaustively/standardized, without any deviations, creating value and eliminating wastes.	A standard for how to manage indirect processes, such as meetings, information flow, project or individual tasks must be created, maximazing value and eliminating wastes.
Time-bounded	Bound rigorously by a defined start and finish	Not time-bounded, which means there is always a constant interaction with the customers, in order to meet their needs.
Types of waste	Over production: consumption of raw materials before they are needed, wasteful input of personnel and utilities Transportation: all sorts of transport (trucks, forklifts, conveyers) Waiting: when the hands of an operator are idle Inventory: stocking items not immediately needed Motion: any motion of a person's body not directly related to adding value, not working according to work standards Over processing: inadequate technology, design leads, unproductive striking, deburring Defects: rework, machine rejects, damage of expensive jigs or machines	Over production: extra analysis and studies, too much information, unnecessary stages. Transportation: flow of information and information sharing, ineffective communication Waiting: delay due to approvals Inventory: redundant, stoppage in information and data system Motion: wrong flow of information to people, seeking for unessential approval Over processing: unnecessary analysis and circulation of wrong decisions and out of place information Defects: innacurate data handling due to inneficient planning and capacity spent in waste activities

Table 3 - Lean Manufacturing vs Lean Management

In presenting the differences between Lean Manufacturing and Lean Management, it is possible to conclude that both are not that different. If a Time To Market (TTM) perspective in developing new products is considered, the value stream is comparable to the manufacturing value chain. Lean Manufacturing can be defined in simple terms as producing exactly what is needed, when it is needed, with the minimum amount of resource and space (Al-Shaab and Sobek II, 2013). As it is possible to perceive in Table 2, waste is more visible in factories, rather than in indirect areas, which enables an easier implementation of Lean Thinking principles. Although there are many differences, both paradigms derive from Lean Thinking, which is applied in different contexts and sectors, focusing on the creation of value and waste elimination.

2.5. Lean Management Challenges and Benefits

Although the Lean Thinking methodology is being applied and implemented with notable success in companies all around the world, regarding the manufacturing sector, not all companies are successful in implementing lean concepts to indirect areas, such as in management and administrative sectors. Thus, Table 4 provides a set of Lean Management challenges identified in literature.

Scholar	Challenge
Sorli et al, 2010	Measure the readiness and level of adoption of lean thinking principles in current industrial practice of management processes by using performance measurement that considers human resources, technology factors and processes of an enterprise; Understand how management processes are structured and what is needed to streamline the process to maximize value creation; Ensure the concurrent generation of lean management design and consideration, as well as the design of its associated lean manufacturing system that is highly responsive to the changing market requirements and production technologies; Select Key Performance Indicators (KPI) to measure the progress made after implementing lean management Improve actual self-assessment tools that are not web based and do not provide functionalities to easily report the assessment results in an automatic way
Dombrowski and Zahn, 2011	Types of waste differ from the types of waste in production as defined by Taiichi Ohno
Khan et al, 2013	Barriers to innovation Communication issues Knowledge-related problems Cultural and organizational barriers

Table 4 - Lean Management Challenges

Regardless of the company's area of business, a necessity to perform in an efficient and effective way as become mandatory. To aid in this task, Lean Management can be a powerful ally. Lean adoption into the management process enables the creation of competitive advantage in comparison with competitors, as it allows cost reduction, through waste elimination and value creation. Lean Management model is able to gauge the maturity of process development and identify the value streams which will enable the company to target the key areas for improvement. As it contributes to a knowledge rich environment, engineers and managers can make faster, more informed and effective decisions earlier in the TTM process. These earlier decisions significantly impact the efficiency and performance of the Product, Suppliers, Manufacturers and End-users in the product lifecycle.

Also, it is important to clarify that Lean Management does not concern only the process improvement, as it contributes also towards the creation of a kaizen culture, affecting day to day activities of managers, what they view as relevant, problematic, and worth communicating, in other words, Lean Management efficacy increases by learning in action (Dutton, 2014). It represents a strategic approach that values employees' improvement and empowerment highly, in order to assure high quality and innovative products.

In sum, Lean Management is presented with many benefits, regarding change of employees' mindset and creates a value-focused and customer-oriented process.

3. Research Aims and Methodology

3.1. The context and goals of the research

This project aims to understand how the successful implementation of a new Lean Management framework can positively impact the performance of management processes, in service support areas to the manufacturing.

The research lasted 8-months, based on the evidence and extending concepts and theories from Lean Management literature. To be successful, a Lean Management framework (case study company initial state) needs to be developed and tested in the field study, through an Action Research (AR) approach. AR also aims to evaluate whether the directive approach is suited for the purpose of stimulating lean application in Indirect Areas.

The present thesis is based on the AR process within a study of a Lean Management framework applied in a manufacturing company, focusing, in particular, on two issues:

- The organization, i.e. creating a organizational culture based on continuous improvement principles.
- The process, i.e. the various management phases and steps the company goes through to develop a prototype, according to customers' requirements.

In particular, this paper aims at answering, through the AR empirical evidence, the following research question:

"How can companies implement successfully a Lean Management framework, able to impact Prototype Production Management processes' efficiency?

3.2. Research methodology

In order to develop a structured research upon a real case scenario in a manufacturing company, an AR methodology was used. This process has been chosen as the best way to develop theory on a new approach, that does not yet exist in the company practice. The main characteristics of the AR are the following (Cagliano et al, 2005):

- It focuses on research in action, rather than research about action;
- It is based on a preliminary theory that is tested and refined on the field;
- It is a cyclical process of planning, taking action, evaluating the action, and leading to
- further planning and so on;
- Members of the system, which is being studied, participate actively in the cyclical process;
- Researchers participate actively in the process, purposefully influencing the system.

Action Research aims both at achieving practical results on the field as well as developing new knowledge. This process was performed during an internship in a manufacturing company in Aveiro, where it was possible to come into contact with Lean Management methodologies, concepts and tools applied in the Industrialization Department.

3.3. The action research process

The AR process was organized throughout an 8-month project that took place from September 2015 to April 2016, where researchers provided new contents, assignments were set, work was performed and results were presented to the administration. All the actions were performed by the employees and managers (members of the system), supported by the researcher. The researcher had both the role of supporting the activities and observing the process, in order to gather relevant information for the research.

The proposal of a new Lean Management framework is mainly to provide help to all companies to achieve success through fundamental stages and steps of a Lean Management philosophy, based on the five dimensions represented in Fig. 6.

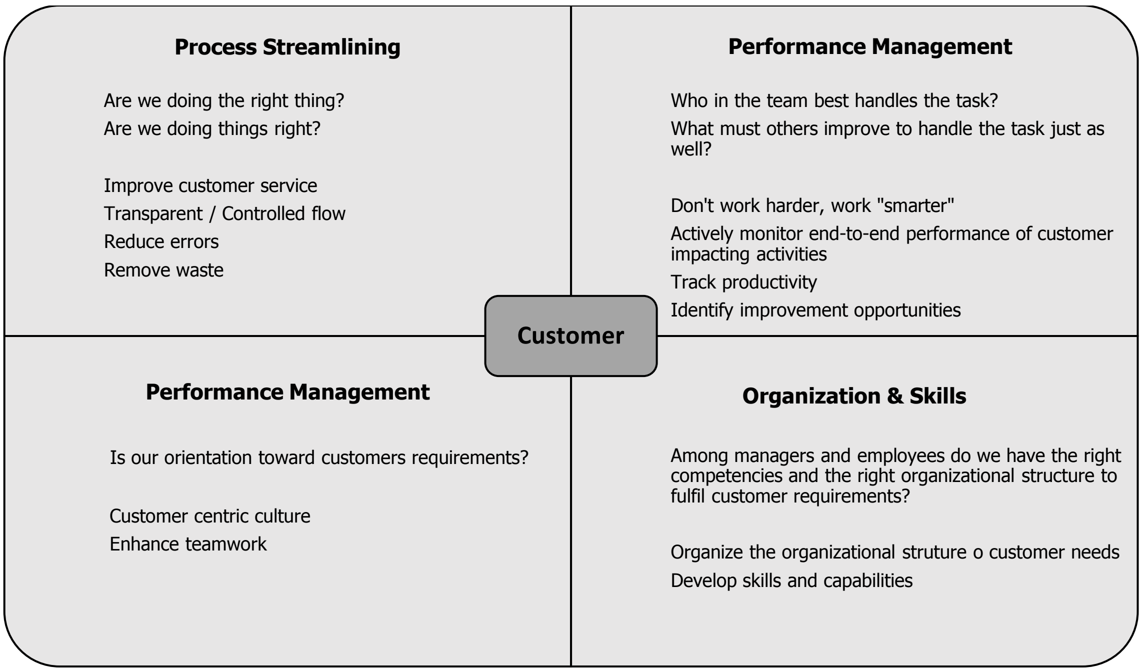


Figure 6 – Lean Prototype Management framework proposal: 5 dimensions

3.4. Case study company

This thesis reports on the AR performed in *Bosch Termotecnologia S.A*., in the Prototype and Samples Production area, regarding a Lean Management Project focused in applying lean methodologies in the Industrialization department. The focal company was established in 1977. It is an international leader, manufacturing hot water and heating systems, whose core business is to produce solutions that are both energy efficient and environmental friendly. The Company's success deeply depends upon product performance, regarding innovation, quality, cost and delivery; essential conditions to conquer new markets and increase its market share.

The AR process was initiated in the focal company to fight against some emerging challenges, by establishing future goals to achieve a better definition of both organization and prototype development processes, resulting in an efficient and flexible flow of information, people and materials, represented in table 5.

Challenges	Goals
Focal company with flat or even no growth - Rising pressure on costs and structures to compensate cost increases and to reach result improvements	With Lean Management the aim is to support managers to establish a new culture of leading and collaboration and thereby focus on improving performance and solving problems in a sustainable way
Main markets in Europe showing an additional phase of stagnation as well as an increasing competitive situation - Increase of low-cost competitors	To reach the challenging targets, the effective assignment of existing resources and alignment on the customer' s benefit are important action fields
Further overall cost cutting and structural adaptations lead to a loss in company performance and overloading of associates - Emerging countries with lower average wages compared with Portugal	Lean Management will help to accomplish a platform for associates to address daily problems and solve them in a sustainable way; the daily routine allows to solve the problems on short notice and without time delay
How to further reduce cost of indirect functions without losing performance, people motivation and customer satisfaction?	By applying the balanced and holistic approach of Lean Management in Aveiro, it will be possible to achieve result improvements as well as improvement of both employee and customer satisfaction

Table 5 - Bosch Termotecnologia S.A. challenges and goals

4. Lean Prototype Management Framework Proposal: Preparation Diagnosis, Design, Implementation and Sustainability (PDDIS)

Due to the present global pressures, an urge in companies is present to do better with less from a short-term perspective. The long-term survival of organizations may very well depend on their ability to introduce new product, better, faster and customer-oriented, by multiple interactions between departments and suppliers, customers, production and process management likewise. This emerging need obliges companies to go under a lean transformation, able to achieve an efficient and flexible processes, and therefore, prototype, development process. From this, we can highlight LPPM (Lean Prototype Production Management) as being critical in manufacturing companies. The lack of current research on LPPM creates some uncertainty about what exactly LPPM is (no universal definition), whether there is real empirical evidence of the success of LPPM, and maybe even more importantly from a practitioner perspective, how to introduce LPPM in environments that are non-repetitive and non-sequential.

In order to initiate, perform and sustain Lean Management in the service support of the prototype production area, companies need to go through a series of steps and undertake a sequence of actions, as represented in Fig. 7.

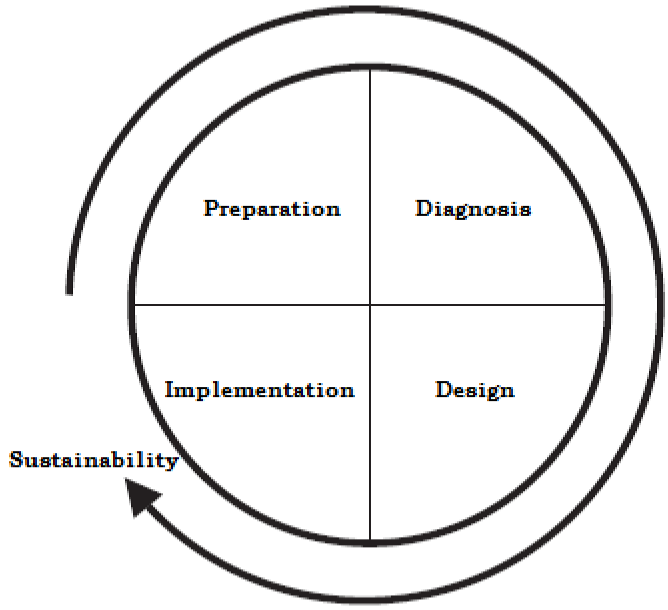


Figure 7 - PDDIS Framework

4.1. The Framework Presentation

The PDDIS framework was designed to be user-friendly, aiming to address companies' lack of knowledge applying LPPM philosophy to prototype management processes.

All stakeholders must participate actively and be involved in the process, in order to raise awareness about the topic and ensure sustainability of the methods, concepts and tools applied. This active participation creats a kaizen culture, which means, suppliers and customers need to be carefully identified and assessed about current performance of the engineering department, concerning improvement points, communication, capability to react to changes, performance and service level. PDDIS framework activities should be carried out daily, with a permanent interaction between researchers, managers and associates.

The market is highly competitive, which implies companies have to seek a way to differentiate from competitors every day. PDDIS framework represents a competitive advantage as it acts as a system of highly interwoven components, which only in their concurrency will lead to an efficient and customer-oriented process, able to react to customers' demand changes. Thus, companies must take into consideration a real case scenario, with valuable tips about what to do in each phase, represented below.

4.1.1. Stage 1: Preparation

This is the first stage of the PDDIS framework. To start, a research team and a project leader must be set-up. Preparation is essential to perform an initial assessment about the industrialization department, regarding the prototype production process, specific functions, initial hypothesis (improvement points), through data, information flow and stakeholders' analysis. From this, researchers need to define targets and a roadmap. Broadly speaking, during this stage, background awareness must be created, in order to avoid misunderstandings or even mistakes.

Preparation is essential to create a solid backbone for the project. Based on the step I proposed by Chen & Cox (2012), several topics should be taken into consideration:

1. Project Structure / Organization chart
2. Scope of the project
3. Stakeholders analysis (find hypothesis, collect observations)
    - 3.1. Employee Survey
    - 3.2. Needs
    - 3.3. Objectives
4. Communication Plan
5. Checklists
    - 5.1. On the site logistics
    - 5.2. Transformation Areas
6. Project Plan
7. Initial Position definition
8. Program target

In order to conclude this stage, a boot camp must be organized between researchers and R&D managers, where PDDIS framework is presented and discussed, and both parties involved in the improvement process interact. The next stage can now begin.

4.1.2. Stage 2: Diagnosis

This is the second stage of the PDDIS framework. After gathering all the necessary information, it is time to go to Gemba. This stage is characterized by great interaction between researchers, managers and the shop floor, as well as observations of daily routines, in order to find hypothesis (improvement points).

During the Diagnosis, the Design and the Implementation stages, several tools can be used to analyze and group the information through the five dimensions of LPPM (see Fig. 8).

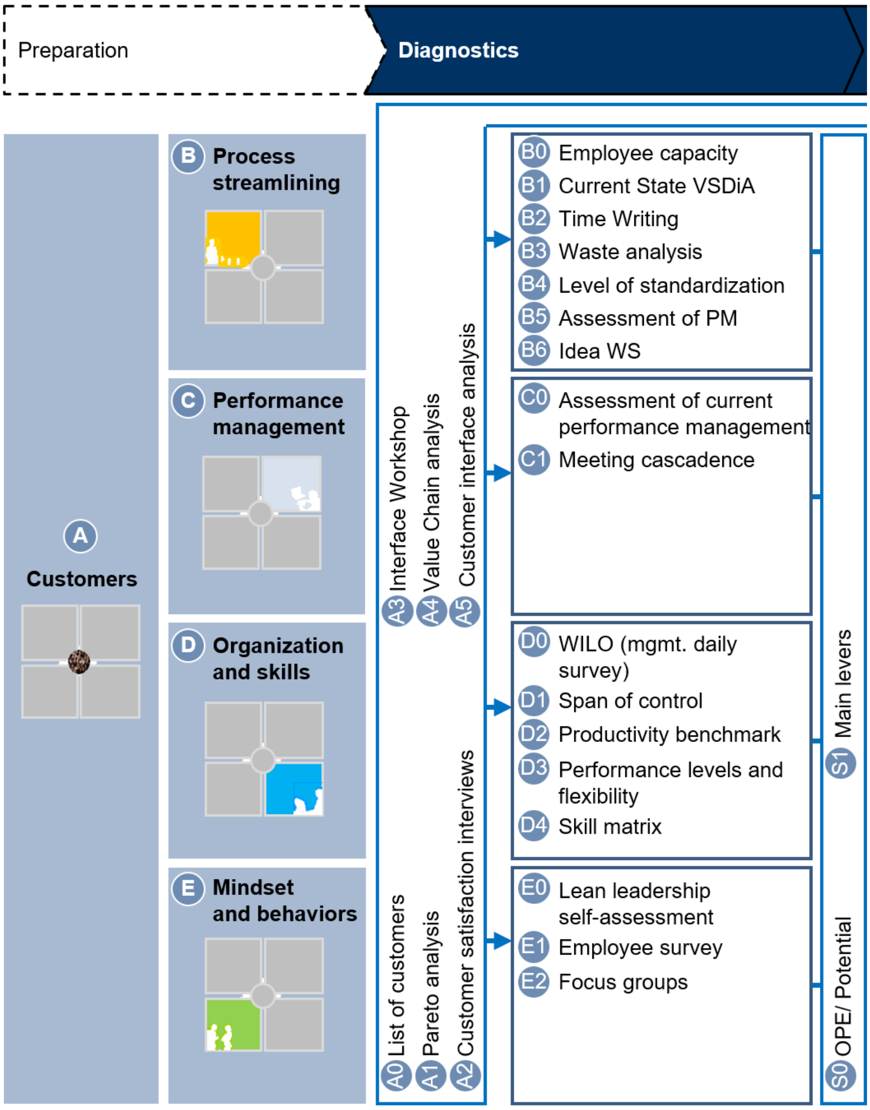


Figure 8 – Diagnosis Tools

These are useful to create background awareness, understand the prototype management process, identify existing wastes and consequently identify improvement areas. The output of this stage are the Main Levers, essential for the next stage of the LPPM.

4.1.3. Stage 3: Design

This is the third stage of the PDDIS framework. With the main levers obtain, from the output of the Diagnosis, the stage to design and create the future state must start. In this stage, it is mandatory to focus on planning the improvement actions and define responsibles for the following stages: implementation and sustainability. According to the diagnostic tools, it is essential to define efficiency gains for each activity, concerning each main lever, in order to establish an efficiency target that is higher than 10%. Sometimes, there are some barriers or lack of commitment from managers, which must be overtaken with a correct and wise plan of how to move from current state to future state and to commit collectively to the objectives and to the defined plan. The department's commitment, regardless of the hierarchy, should be ensured by top management.

During this stage, it is mandatory to define Key Performance Indicators (KPIs) in order to measure the improvement throughout the five different dimensions. With the focus on the main levers, which are the main improvement opportunities across the five dimensions, several solutions must be created to fulfil those opportunities, counteracting the problem presented by each main lever, or key lever, in preference, more than one for each lever.

Afterwards, the steps to fulfil each solution and the corresponding efficiency gain, must be defined and specified in a time scale of implementation, creating the Tactical Implementation Plan (TIP), the main output of the Design stage, whom offers guidance for the Implementation stage. Several other tools can also be applied, such as the Whiteboard layout design or the Meeting Cascade. In order to understand these tools templates of each one are represented in Fig. 9.

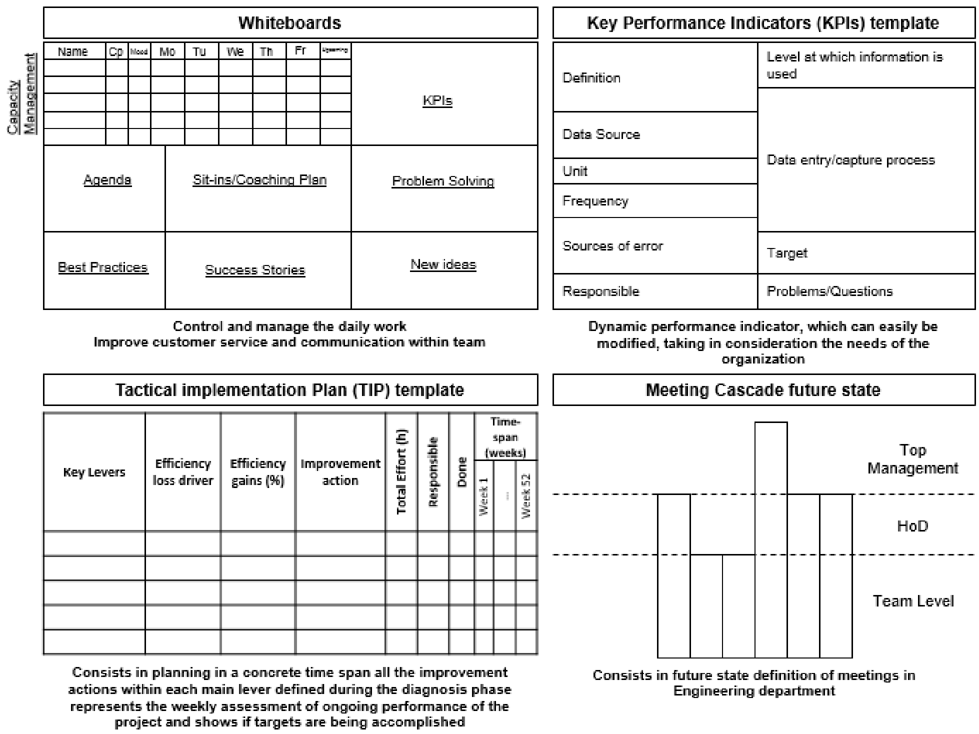


Figure 9 - Design Tools

With the future state aspiration tools defined and finalized, and each main lever with several solutions to counteract the problem described by it, each solution with several steps of implementation spread along a timeline, each one with an expected efficiency gain and a team member responsible to implement it, the project is with enough maturity to move to the Implementation stage.

4.1.4. Stage 4: Implementation

This is the fourth stage of the PDDIS framework. The improvement activity was planned, allocating resources and defining the actions needed to achieve the desired results. The plan was then executed, through the development and implementation of the solutions that emerged from the TIP. During this phase, employees try and learn the new way of working, with the support from researchers. All employees should be aware of the importance of the TIP and its improvement actions, in order to assure that the efficiency gains were achieved. At the end of this stage, there should be a visible impact of Lean Prototype Management principles, methods and tools on teams, management and KPIs, resulting from a joint workforce: employees and managers. To achieve this knowledge, during the diagnosis, design and implementation stages, first managers and then employees attend workshops and trainings, performed by researchers about the 8 lean fundamental blocks (see Fig. 10).

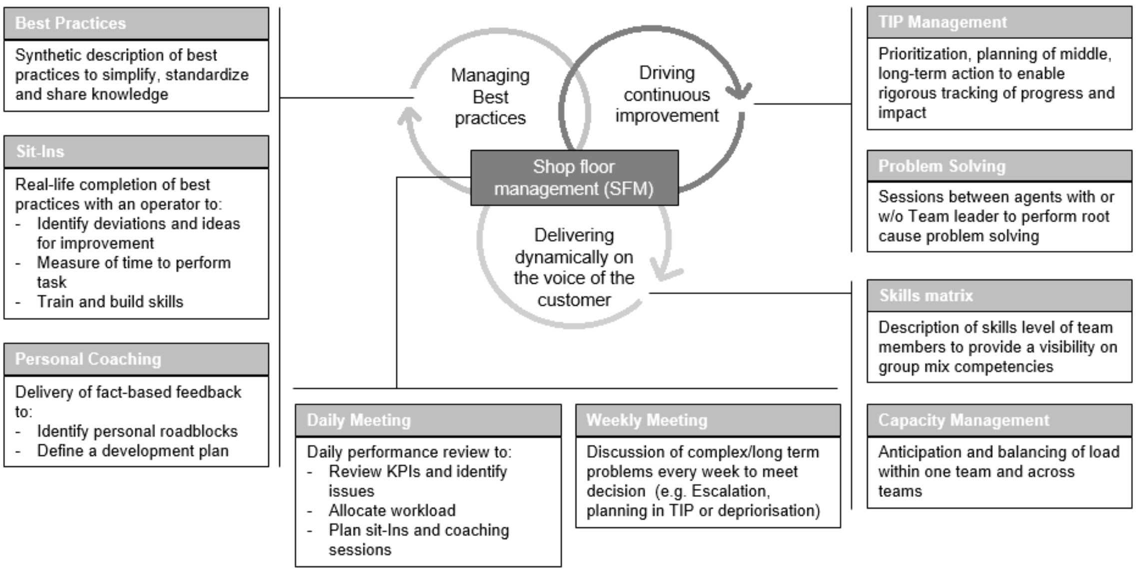


Figure 10 - The 8 Lean Building Blocks

4.1.5. Stage 5: Sustainability

This is the final stage of the PDDIS framework. Sustainability Phase is a cyclical phase, and a critical one, a review of all previous stages that aims to create a new working culture, based on changing habits. In order to ensure change and sustainability of the methods used, employees must act autonomously, carry on with improvements, measure gains, make reports, act according to a transparent, committed plan and improve maturity levels in each one of the 8 building blocks, taking the necessary measures to reach the target.

Sometimes, the Tactical Implementation Plans are too ambitious and many tasks need to be completed during the sustainability phase, so it is necessary to structure a new tactical plan: Sustainability TIP, or OPL (Open Points List). This new plan should include unfinished tasks from the implementation phase and new improvement actions, with assigned gains and responsibles, as presented in Table 6.

Open Points List						
Date raised	Topic/Cluster	Problem Description	Benefit (0-10)	Effort (0-10)	Due date	Responsible

Table 6 - Sustainability TIP Template

4.2. The Framework Application

As stated in chapter 4, this framework was applied in a manufacturing company, with the aid of an Action Research process. This AR allowed the examination of some focus internal structures of the organization, as suggested by the preliminary theory, identifying strengths and weaknesses. One of the first key elements is the presence and proactivity of every stakeholder, regardless of hierarchy. The commitments with the targets and the involvement in the process from the beginning are essential, in order to build a collaborative and co-operative environment, otherwise, a continuous improvement culture will not be sustainable.

In this project, regarding the Prototype Management Process, the Technical Department (TEF) was divided into five Groups, and some in Teams:

1. TEF1 – Maintenance,
2. TEF3 – Industrialization,
    2.1. TEF3.1 – Industrialization Project Management,
    2.2. TEF3.2 – Industrialization Engineering,
    2.3. TEF3.3 – Process Development,
    2.4. TEF3.4 – Prototype Production,
3. TEF6 – Times and Methods
4. TEF7 – Industrial Network Security
5. FCM – Facility Management
    5.1. FCM1 – Industrial Facility Management,
    5.2. FCM2 – General Services Management.

The focus present in this thesis is the implementation of the PDDIS framework in a specific team, The TEF3.4 – Prototype Production, in the Industrialization Group. Besides the Team Leader, 3 engineers and 6 operators were present. Although different degrees of collaboration were present inside the team itself, the majority of the team, as well as the rest of the stakeholders involved (the Industrialization Group Leader and the Head of the Department) were committed to improve the team, and there for, the company's performance. Other examples of Lean methodologies and techniques are present inside other teams and groups in the company, each one with the customization required to achieve the team specific targets and create a kaizen culture within it.

When the project started, one major goal was defined: Reduce the waste in the TEF3.4 in 10%. But a question emerged: How to achieve waste reduction in order to create added-value to meet customers' requirements?

The PDDIS framework presented was applied during 6 months in the TEF3.4, to whom each one of the stages of the Lean Prototype Management and the PDDIS were explained in detail.

4.2.1. Stage 1: Preparation

The project started with setting-up a team (a project leader, or lean navigator and some lean consultants). During this phase, it is important to create background awareness. Therefore, researchers initiated this process with a stakeholder analysis, through emails and telephone calls, having found some hypothesis (improvement points), such as: too much time to answer an email, no clear understanding about department roles and targets, lack of support to employees and a general lack of information. To complement this analysis, information about employees' performance and flexibility to perform tasks was gathered, as well as employees' satisfaction, through a survey regarding direct management (form present in Appendix I).

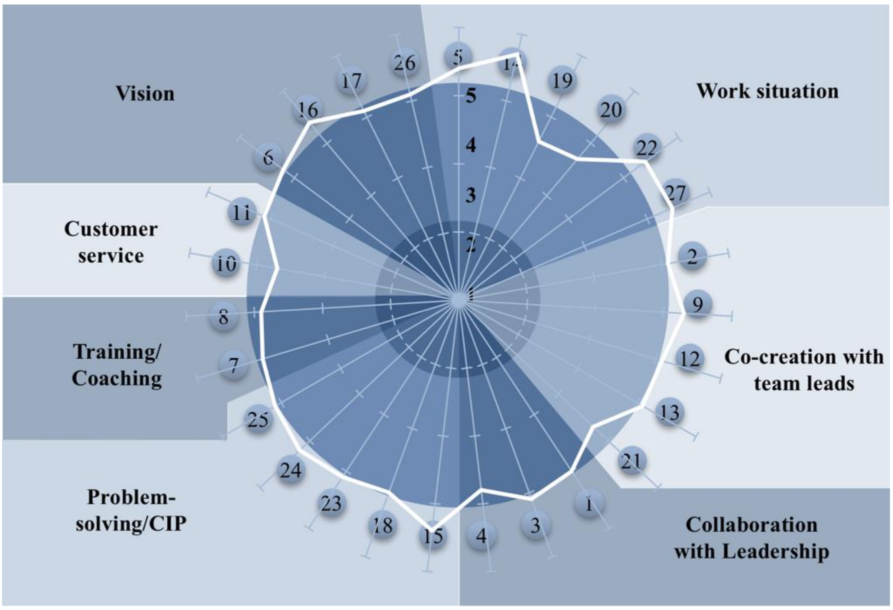


Figure 11 - Employees' Satisfaction

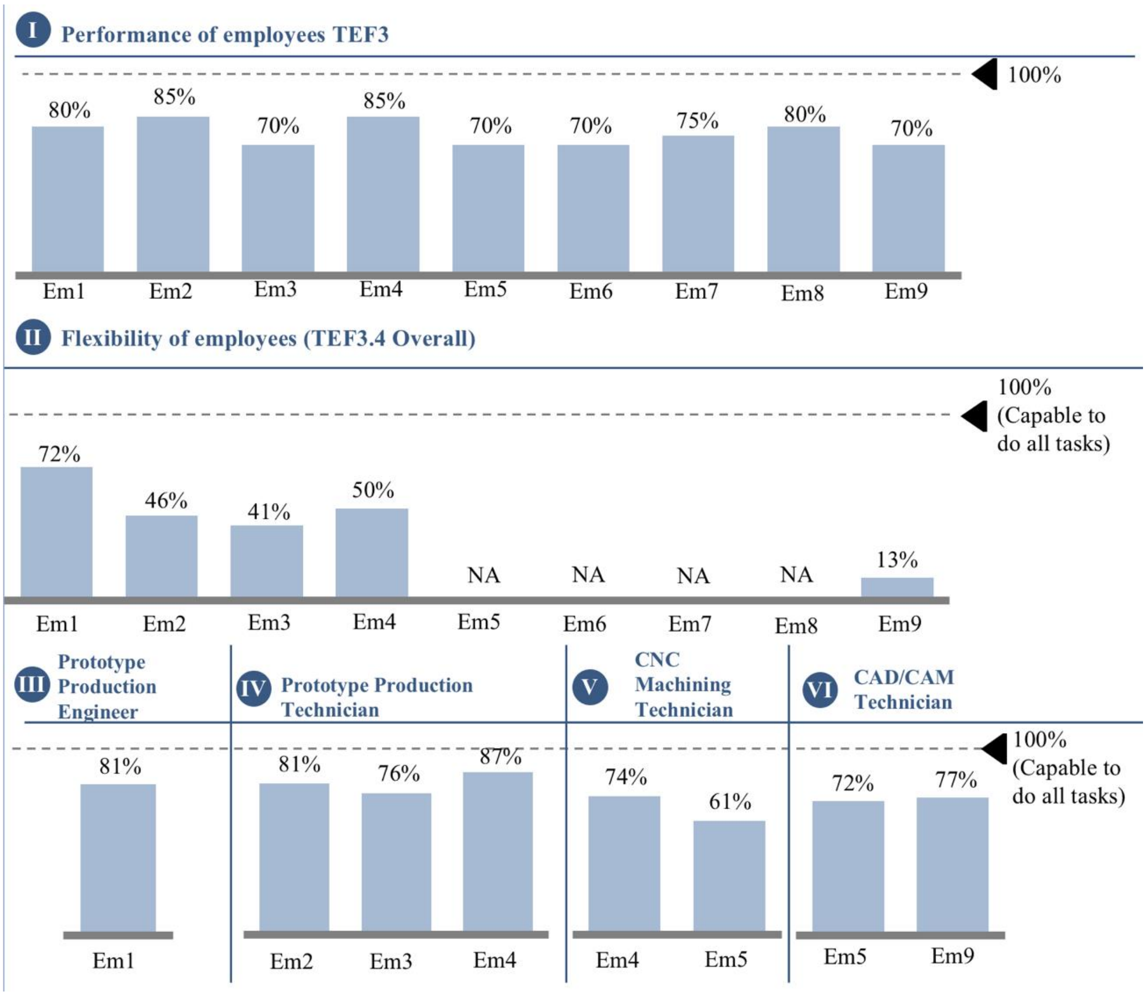


Figure 12 - Performance and Flexibility of Employees

In the Figure 12, three different categories of charts are present. In the first, regarding the performance of employees, a measurement of the expected output versus the real output of each employee is present. This KPI was measured and analyzed during one month, using the tasks attributed to each employee on the white board meeting, and the expected delivery date of those same tasks. In the second one, regarding the flexibility of employees, an analysis regarding all relevant skills present in the TEF3 group was made. Since the TEF3 group has 4 different teams, each one with a different focus, a more detailed analysis was made, for each of the 4 different areas within the TEF3.4 team, in the third to sixth chart. In this case, each employee was only evaluated by the necessary skills of the area he was present (his job description).

With these measurements, some gap is noticeable between the level of skills present in each employee and the need level to perform the necessary tasks. Therefore, from the application of this tool, some coaching and training is advisable to reduce the skill gap, to lead to an efficiency increase.

Finally, in order to prepare the upcoming phases of the project, a Lean motivation boot camp was organized. During this 2-day activity all the participants were confronted with the core elements of Lean Management (8 fundamental building blocks), that became familiarized with the PDDIS framework tools and with a standardized method for conducting a lean project (project plan and targets for each phase, employees' benefits and a lean change model, based on four main categories: Insight, Skills, Systems and Culture/Role model). This activity was very important because it joined managers and researchers, provided insights about lean concepts, principles and methodologies and the preliminary theory was presented and discussed with the participants. This initial phase impacts the overall perception of managers about lean and its importance to perform better in a continuous improving and sustainable way, as presented in table 7.

Participant	Comment
Production Technician	Lean motivation boot camps are very important to interact with project stakeholders, connecting the management and the technicians, debating everyday ground floor issues. It also enables participants to increase their knowledge of lean tools, through role playing and discussion sessions.
Team Leader	This activity before the official start of the project onsite is fundamental, as it represents a joint event, where both managers and technicians interact and get to know each other, discussing project targets and plan. Because, many concepts were unfamiliar, during these 2 days it was possible to understand and become familiar with the main tools, applied during the project.

Table 7 - Lean motivation boot camp participants' feedback

4.2.2. Stage 2: Diagnosis

In order to initiate the project onsite, the first step towards a lean transformation was done by dedicating a first session to explain the meaning, importance, benefits and critical aspects of the lean concept and respective methodologies, in addition to the project scope.

This was a fundamental phase as it concerned the application of diagnosis tools, enabling initial hypothesis confirmation and the identification of new ones, as well as understanding the product development process, its stages and possible existing wastes.

Diagnosis represents one of the most important stages of the PDDIS framework, because it is characterized by the application of fundamental tools, presented before, in fig.7.

Customer	Deliverable	Effort spend, in percent
ENG2.1	Prototypes (Heat Pumps, Boilers, Combustion Chambers, Copper Pipes, Boxes, Burners, Supports, Machined Components, …)	53%
ENG1.2	Prototypes (Heat Pumps, Boilers, Combustion Chambers, Copper Pipes, Boxes, Burners, Supports, Machined Components, …)	16%
TEF3	Industrialization support	10%
Others	General Work	9%
ENG1.1	Prototypes (Heat Pumps, Boilers, Combustion Chambers, Copper Pipes, Boxes, Burners, Supports, Machined Components, …)	8%
ENG Geral	Prototypes (Heat Pumps, Boilers, Combustion Chambers, Copper Pipes, Boxes, Burners, Supports, Machined Components, …)	4%

Key take aways:

- Although some effort is spent with TEF3, the main customer is clearly ENG, mainly ENG 2.1 and ENG 1.2.
- Some quick jobs and quick fixes are done to a diversity of different departments across the plant.
- TEF1 with growth prospects as a customer in the next years.
- The variety of possible deliverables is considerable, as of possible customers. This is duo to the high diversity of machines and skills combinations present in the team, and to the lack of standardized processes. Each order is an unique one, requiring different processes.

Figure 13 - List of TEF3.4 customers by effort spent

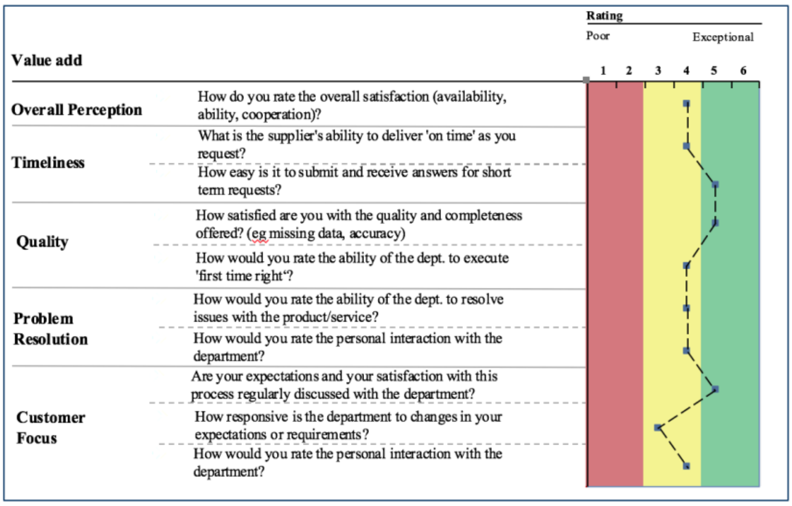
In the Figure 13, an analysis of the TEF3.4 customers is present. It was performed taking in consideration the number of working hours spent per customer from January 2014 to October 2015. Unsurprisingly, the ENG (Research and Development) Department comes as a major customer of the Prototype Production Team, although some support is also provided to the other TEF3 teams, besides some general work. The main customer is the ENG 2.1 group, responsible for the development of fan pressurized instantaneous water heaters, followed by the ENG 1.2 group, responsible for the development of unpressurized instantaneous water heaters.

With these measurements, it was possible to know which are the main costumers, the ones to gather feedback from and the which could be improvement opportunities with the most impact on the efficiency of the team.

After the customer analysis by effort spent, interviews were performed to the group leaders of the 3 main customers (Fig. 14.). From these interviews, a summary and some takeaways present in the Figure 14 were possible to retain. With these outputs, it was possible to determine which were the improvement opportunities.

Summary of interviews with Main Customers:

- ➔ Customers appreciate the quality of the products delivered;
- ➔ Necessity to improve LT in order to deliver the products on time;
- ➔ Customers see need for further improvement in overall communication.

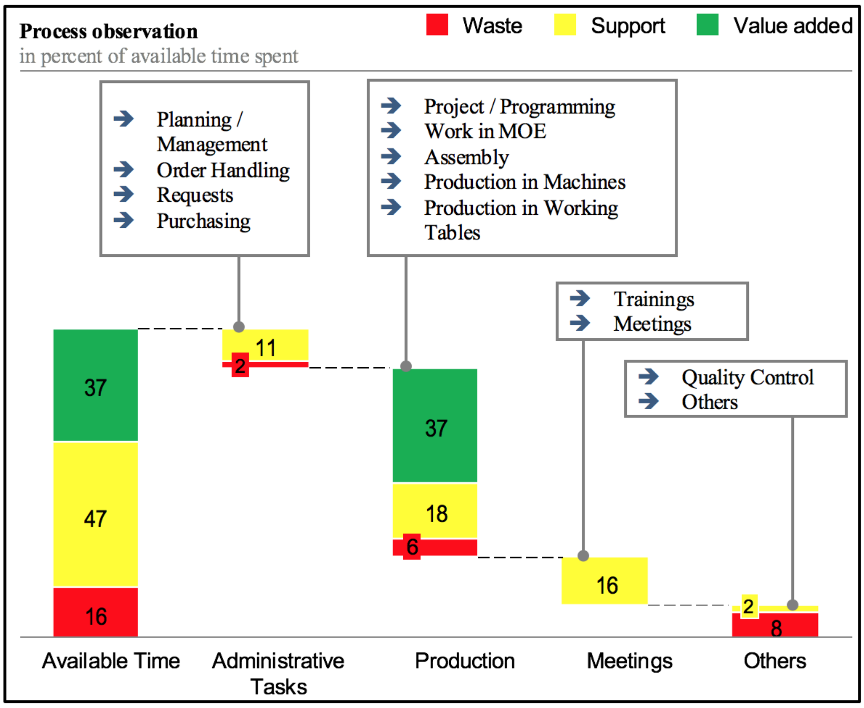


Key takeaways

- ➔ **Delivery on time** and ability to execute "**first time right**", must be improved!
- ➔ There is a necessity to **improve the problem solving overall area.**
- ➔ **The TEF3.4 is not very responsive to changes in expectations or requirements**
- ➔ The interaction between departments could be better.
- ➔ By improving this areas, the **overall perception will improve.**

Figure 14 - Customer Interviews

In the Figure 15, a time measurement was performed. First, a list with all possible tasks performed by the team was created. Afterwards, each task was classified in waste, support or value added. Finally, during a period of one month, the time spent by the team in each activity was measured and compiled.



Key take aways:

- ➔ 16% of the Teams Capacity is spent in Reworks, Movement, Transport, Personal Phone Calls, Waiting, just Talking (4%), and others;
- ➔ 16% of the Teams Capacity is Spent on Meetings/Trainings (FTE=1.6 only for Meetings/Trainings)
- ➔ 6% of the Teams Capacity is spent in Production Reworks
- ➔ 47% spent in Support is a considerable amount for a production area.

Figure 15 - Employees' Operating Time

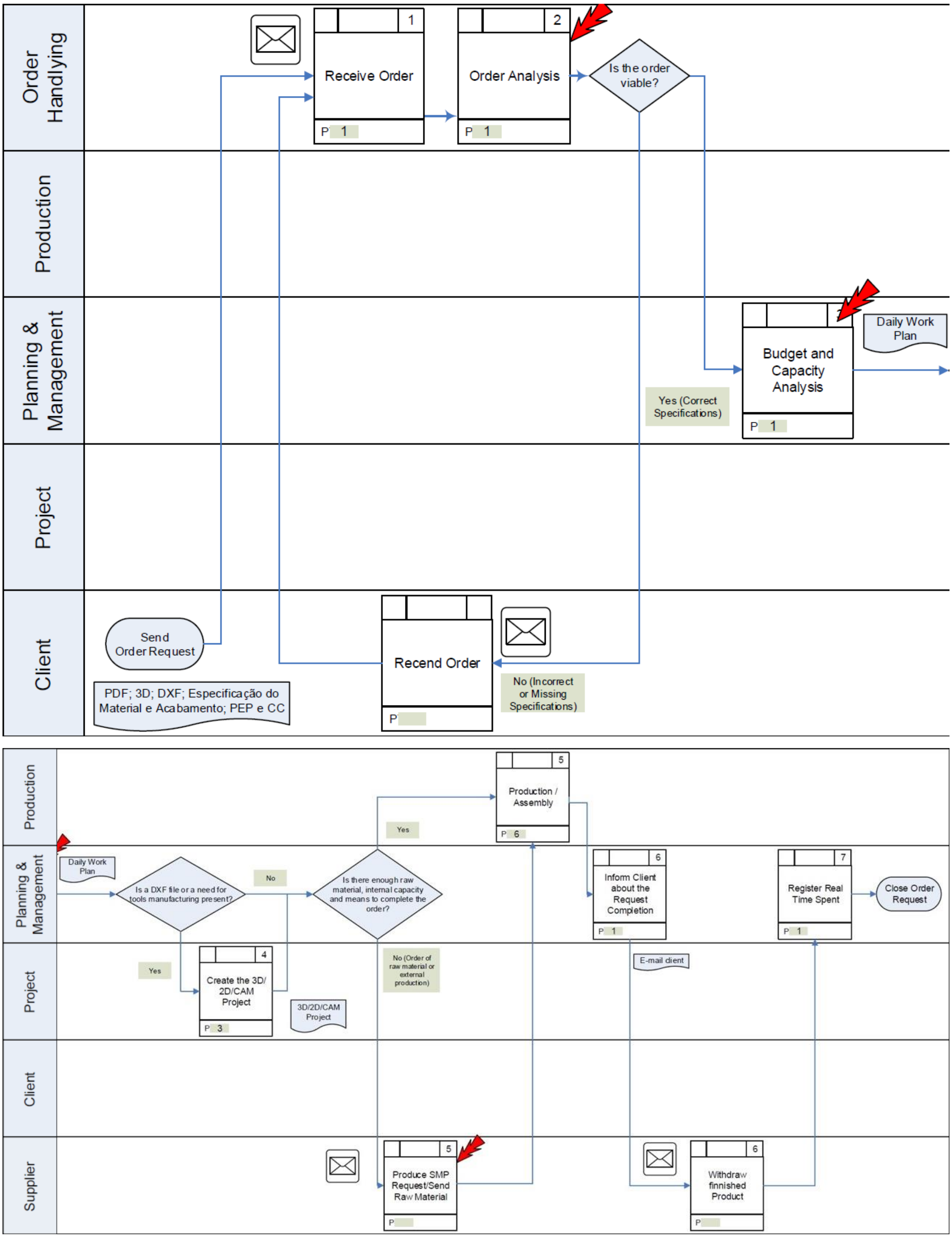


Figure 16 - Current Value Stream Map

In Figure 16, the Current Value Stream Map is present. Marked by red lightning's are the activities with common rework present, and possible focus.

This phase ended with a regular meeting between productions technicians, engineers and management, which aimed to present the main results from diagnosis tools (see Fig. 13 to 16) and main levers identified within the project, for the TEF3.4 team (presented in Fig. 17).

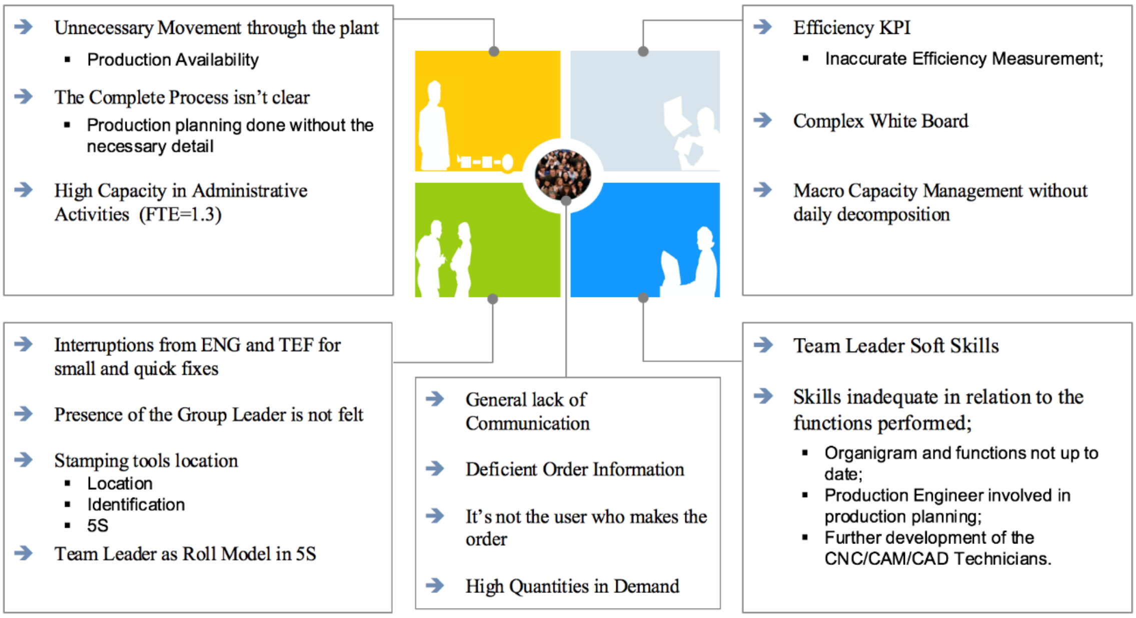


Figure 17 - Main Levers by each of the LM 5 Dimensions

With the main levers identified, becomes easy to understand what needs to be counteracted, in each of the 5 LM Dimensions, to improve the outputs and the team's efficiency. How to counteract them will be created during the next stage, where the new improvement measures are designed.

4.2.3. Stage 3: Design

In the third phase of the project, researchers and managers defined all improvement actions. Design represents a 4 weeks' phase, in which managers are prepared by researchers to act as role models. Broadly speaking, the design phase represents an ultimate stage before implementation, in which the future state of the department is set, regarding improvements, the definition of a tailored KPI system, design of whiteboards and the development of future state skills matrix, with desired levels of skills for each employee.

The whiteboard is considered the driving force of lean ongoing application, because it represents both a daily regular meeting, where managers and team members meet together to talk about daily capacity, problems, performance update and new ideas, and a management board, where all important topics are covered, providing a general overview of team performance and projects status, to control and to better manage the daily work. On the other hand, making a Tactical Implementation Plan (TIP) represents a commitment to improvement actions and future efficiency gains from managers and team members. This tool is an ongoing control tool, where it is possible to identify back spikes (delays) to the plan and actions implemented with success and represents a summary of all actions needed to be implemented, along the project, during the implementation phase. It must be reviewed on a weekly basis, checking if planned actions are being done and implemented with success.

Finally, in this phase, KPIs were set and its frequency of measurement defined, because performance indicators represent the only way to assess the team's growth and development.

KPI	Frequency
Prototype Production Quality	Weekly
TEF3.4 5S Evaluation	Monthly
Prototype Production On Time Delivery	Weekly
Quotation Evaluation Reply On Time	Weekly
Prototype Production Lead Time	Monthly
Number of Open Points Closed in Problem Solving	Monthly
Number of Best Practices Created	Monthly

Table 8 - PDDIS framework: KPI definition

All these tools were designed jointly by technicians, engineers and managers, to better address team needs. At the end of this phase a regular meeting between researchers, managers and top management was organized, which aimed to present the Whiteboards layout, Tactical Implementation Plans and main KPIs defined. This meeting was very important, because it represented a commitment from managers to top management towards the hypothesis identified during the diagnosis phase, and consequent improvement actions and efficiency gains. During this meeting the results of maturity assessment of lean elements of TEF3.4 were also shown, as represented in Fig. 18 (template present in Appendix II).

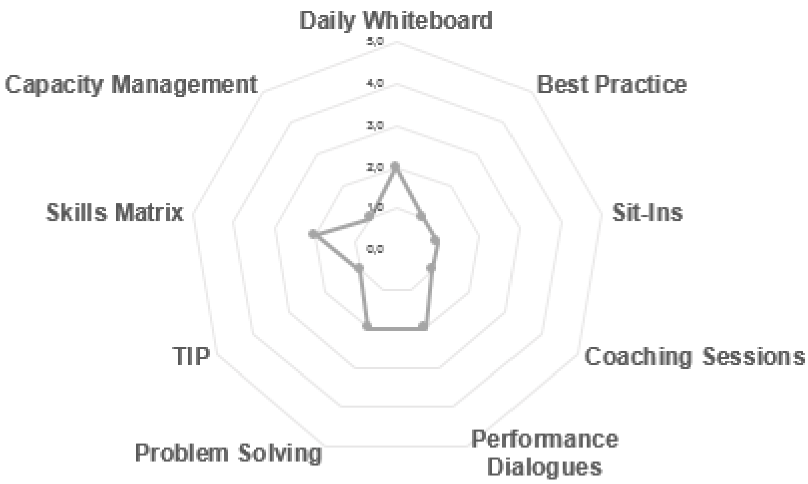


Figure 18 - PDDIS Framework: Maturity of lean elements (Design Phase)

Design tools make a great contribution to design the future state of the team, defining clear targets for the implementation phase and addressing the way wastes and problems are being reduced as well as enhancing a commitment to invest in an organizational culture, set on fundamental pillars: continuous improvement, problem identification and resolution, performance measurement, collaboration and communication, knowledge and sharing success stories, capacity management and personal and team planning.

4.2.4. Stage 4: Implementation

After observing the current state and designing the desired future state, managers started implementing improvement actions, with the researchers' support, according to TIP, represented in Figure 18. Usually, the TIP is represented in excel table, but in order to create a more interdependent, dynamic and user friendly tool, a board with *post it's* were used.

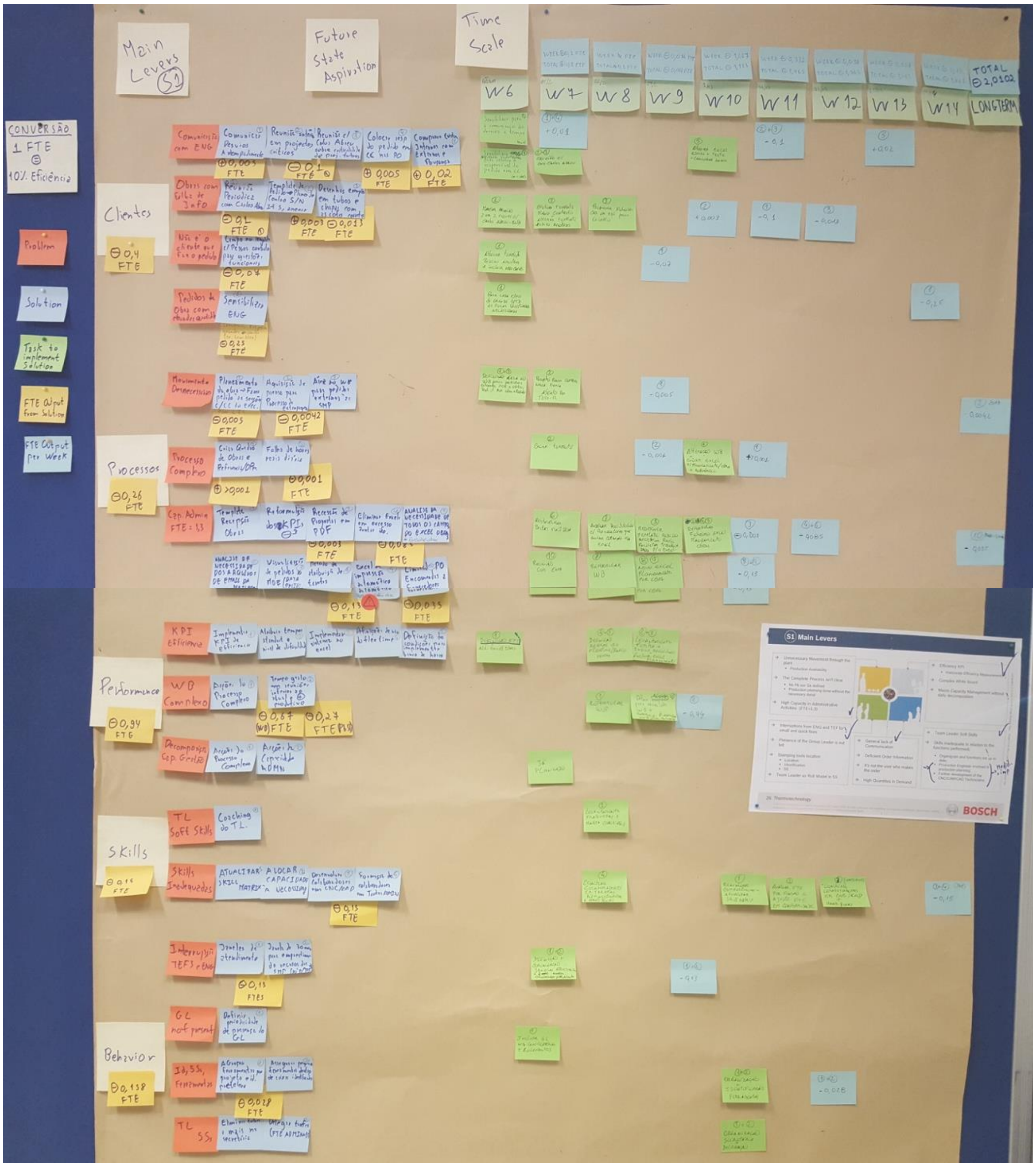


Figure 19 - PDDIS Framework: Improvement actions (TIP)

In the TIP, the Main Levers are organized by each of the 5 Dimensions. For each of the Main Levers (in red), several improvement actions (in blue) were defined (Future State Aspiration). In order to fulfil each action, one or more tasks (in green) must be completed, according to a weekly time scale. Since the improvement will never be visible right after the implementation of the action, requiring some time to gain maturity, in the schedule is also present when these gains would be visible (in light blue). To easily measure the maturity of the system, each week has the achieved efficiency improvement also present.

After fulfilling an action, a certain efficiency improvement is achieved (in yellow), in this case, measured in FTE (Full Time Equivalent). 1 FTE is equal to the capacity spent by 1 person uniquely dedicated to a certain task, or an equivalent of that capacity. In this case, since the team has 10 people in total, it has 10 FTE to distribute in all tasks. Decreasing FTEs in a task is equal to increase the efficiency performing that same task.

The Team Leader and the Navigator had a critical role in generating improvement actions and then implementing them, but during this phase the problems started to appear, due to two main factors: resistance of employees to change and to cooperate, and lack of time to coordinate lean activities and prototype production management (see table 8).

Participant	**Comment**
Engineer	Lean activities do not have an instantaneous impact on my daily work and I do not have the capacity to plan my daily deliverables ahead, because when I am planning an order most of the actions are variable and without a specific time assigned. In addition, KPIs do not have a direct impact on management.
Navigator	The Team Leader and the Engineers faced many problems to implement lean methodologies, because engineers didn't understand the importance of planning activities in advance, were not transparent, were not able to express their daily problems and were always reluctant to changes regarding order planning processes, due to lack of repetitive processes, able to be standardized.
Team Leader	Lean activities occupy a large time slot, which obliges me to work extra hours to meet daily targets. Prototype Production Management Processes are too big to map and I have many difficulties in measuring efficiency gains of improvement actions.

Table 9 - PDDIS framework: Implementation problems

This phase required a strong communication and collaboration between the engineers, production technicians and the team leader. In order to overcome this lack of communication and time to share problems, the TEF3.4 remade the team's whiteboard in order to adjust to the team's necessity. Instead of 1-hour whiteboard meetings regarding order's information which wasn't shared during the order planning, the team could address the mood of each participant in the meeting, existing production problems, KPIs control and best practice sharing. With the standards re-defined, 15-minutes were enough for the meetings.

The whiteboard design was also re-defined, to accommodate the several production operations that were possible to be accomplished inside the TEF3.4 area and at the same time, allow a better order planning detail. Instead of an order planning done by technician (a technician would receive an order to manufacture, carrying it out from start to finish, through the several production operations) – Fig.20, it is done by sequence of production operations (e.g. An order is divided in several references, which one, to be completed, has 4 operations – A, B, C and D. The reference *post it* is placed on the whiteboard, and a technician with skill level to perform the operation A will be in charge of it. When operation A is completed, the *post it* is moved to the operation B, by FIFO, and so on) – Fig.21.

Figure 20 - TEF3.4 Previous Whiteboard

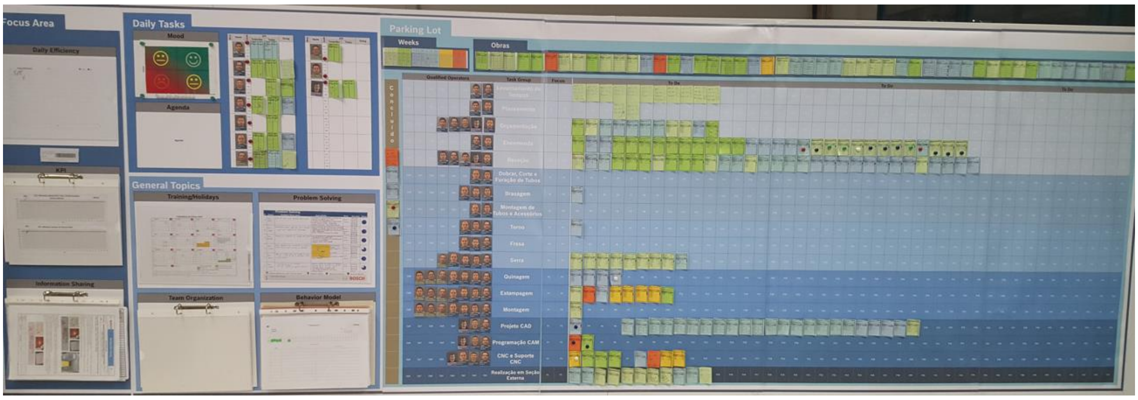


Figure 21 - TEF3.4 Whiteboard redesign

Since an order can contain several components (e.g. A combustion chamber in comprised of pipes, bushings, bended copper sheets, and so on), these components can be manufactured in parallel. So, each order is comprised of several references of components, and to manufacture each component, several operations must be completed (Fig.22).

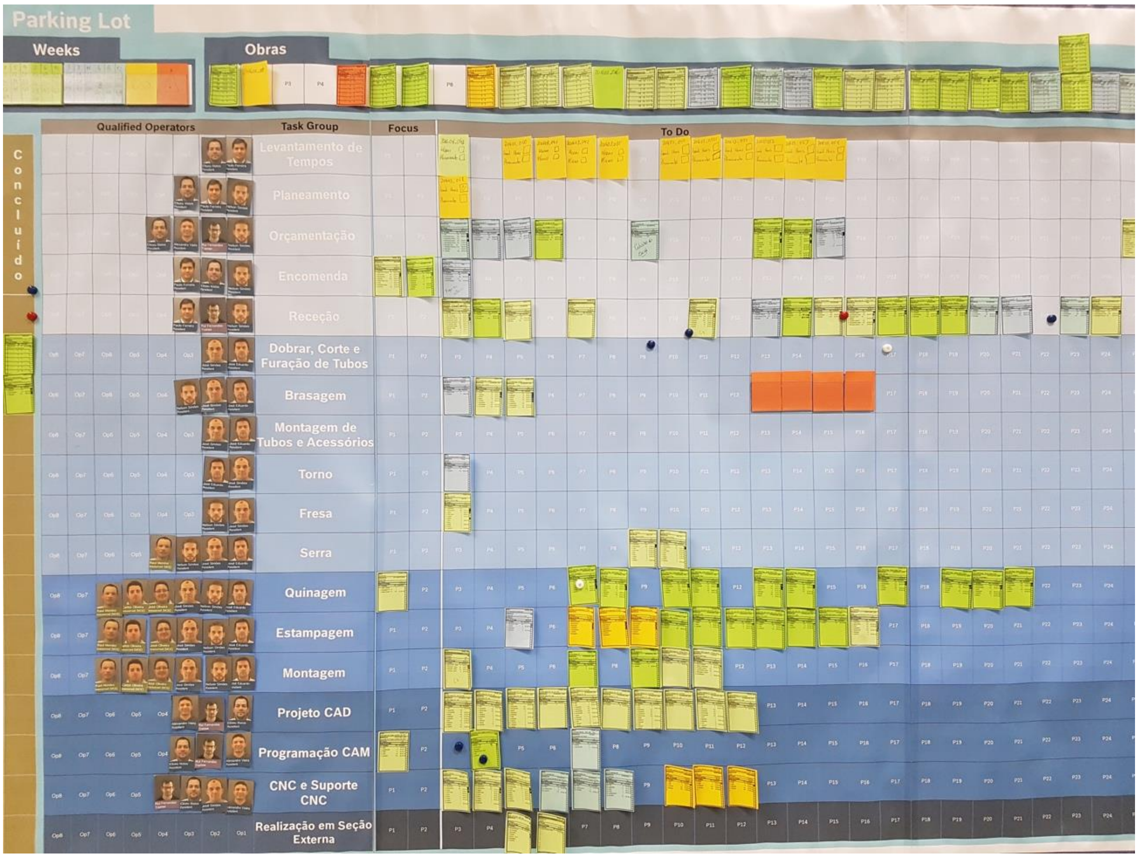


Figure 22 - TEF3.4 Parking Lot

Therefore, a change was present. The level of detail in each *post it* has increased drastically. In order to contain all the information, regardless if it was a reference or an order *post it*, it was not possible to hand write everything in each one. The idea to create a program that would print the *post its* using visual basic emerged.

Previously, the production engineer would receive the order requests, and according to the technical drawings present, he would create an order of tasks to be fulfilled for each reference. This was done by handwriting in a sheet of paper. Afterwards, he would give the sheet of paper with the necessary references and the tasks to complete each one to the team leader, who would write *post it's* and place them on the whiteboard (Fig.20). After this procedure he would open the capacity charge excel of the team where he would increment the hours calculated by the production engineer. This process took somewhere around 4-hours for each order.

After some meetings with the top management, and an analysis of the historic data present on the capacity charge excel vs. the possible output of its fulfillment for each order, this task was discontinued.

The implemented standard for the order analysis process begins also with the production engineer planning the tasks, but now by reference and by order. Instead of the sheet of paper, an excel sheet is used, with a macro which not only improves the creation of each reference and order, but also aids in cataloging the information by order request, and automatically printing all the *post its* (Fig.22). With the implementation of this standard, the process takes around 12 minutes per reference, an average of 1 order per hour, depending on the order specifications.

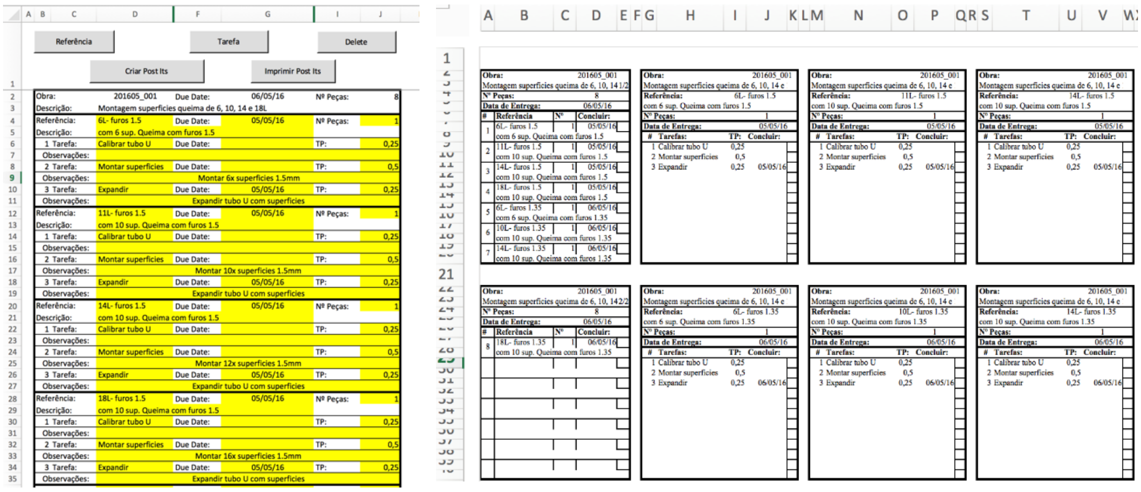


Figure 23 - Order Planning Excel

The production engineer just increments more references or tasks for the order in hands using the macro buttons, and when the order is completely planned, he uses the button to create the post its (right side of the Fig.24). An example of the output is present in Fig.24 (left and center *post its*)

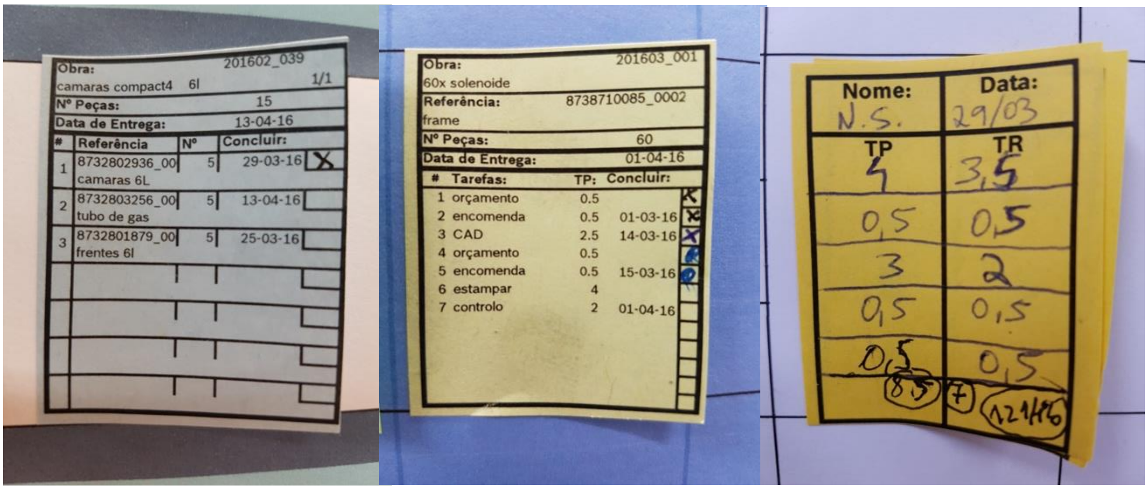


Figure 24 - Order Post It (left), Reference Post It (center), Daily Efficiency Post It (right)

Besides the new organization present in the parking lot, the Whiteboard for daily meetings also changed (Fig. 21, left side). The new layout allows each team member to measure their efficiency, by comparing the real time spent performing a task (Fig.24, right *post it*, "TR:" column) and the time the production planner planned for its completion (Fig.24, center *post it*, "TP:" column).

Due to initial employees' mind-set, whiteboards were performed inefficiently with low focus, being improved along time, during the implementation phase. To complement whiteboards and to meet employees' needs regarding job related problems, inexperience and some difficulties to perform in an efficient and effective way, several coaching sessions, sit-ins, trainings, workshops and problem solving sessions were performed.

Applying these tools showed how engineers were lacking support and openness to share daily problems, share functions responsibility, ask for help and plan and slice/break down deliverables in advance.

The implementation of improvement actions that contribute actively to creating a kaizen culture is the focus of the implementation phase. During this phase many problem solving sessions were held, generating issue trees (see an example, in Fig. 24), with a Mutually Exclusive, Collectively Exhaustive (MECE) description of defined Specific, Measurable, Action-oriented, Relevant and Time bounded (SMART) problems, without an initial root cause. Because problems must be faced as improvement opportunities, problem solving sessions contributed actively to reach solutions together, without blaming anyone, only focusing in identifying root causes and possible solutions. Although not all solutions were implemented, in all cases it was possible to identify root causes and raise awareness about the problem, which will impact on efficiency and team performance.

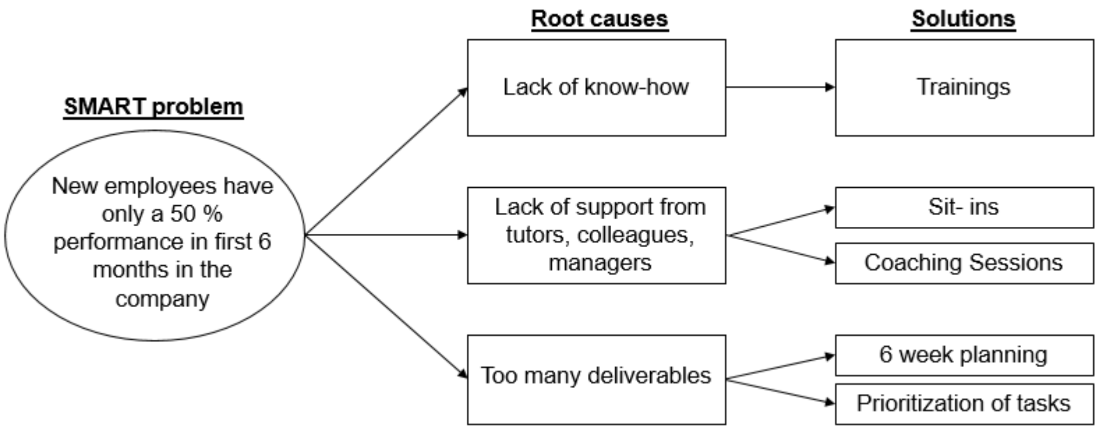


Figure 25 - Issue Tree example

The issue tree, depicted in Fig. 25, helped to understand the reasons behind the low performance of new employees, when they arrive for the first time in the company. From the deployment of this problem, it was possible to define improvement actions/solutions to surpass this recurrent situation and address problems like: lack of know-how, lack of support and existence of too many deliverables (daily activities).

With the new whiteboard and standards regarding the prototype production planning process, some major main levers were countered (main levers present in Fig.18), by making the process and the whiteboard clearer to everyone, creating an efficiency measurement KPI, and decomposing the daily capacity.

Regarding the main levers related with the customers, mainly communication with ENG:

- The responsible for making the order request must place the technical responsible for the project in the email CC, and a mandatory control plan according to a new template created must be attached – This will aid the TEF3.4 team in possible technical questions that may occur;

- Before critical projects, a strategic meeting must happen with the ENG's top management, allowing a better understanding of the deliverables and priorities, preventing reflows of information;
- Every three months, a meeting must happen with the ENG's top management to review the last three months of projects and define new priorities for the upcoming one, optimizing capacity, in order to avoid unnecessary production and compromising more critical projects.

Regarding the processes:

- Although the TEF3.4 area is well equipped to deal with the majority of operations, some tasks must be performed in the general production areas. Since there's a constant production rhythm in this areas, with standardized LT and CT, only in small, and sometimes not schedule breaks, that the opportunity appears to use the equipment present in this areas. To prevent the unnecessary movement of the TEF3.4 technicians to this areas, just to check if the equipment is available for use, a standard was implemented. For each possible area from the general production where the TEF3.4 could need equipment support, the TEF3.4 sends every week an occupation request to use the necessary equipment for the following week. This away, a better planning can be achieved, reducing the unnecessary movement throughout the factory.
- To aid in the capacity of the team leader in some management tasks, the quantity and relevance of the inputted information in excels was analyzed, as well as the repeatability of such information across several documents, including emails. Around 25% of the information was repeated, and only 60% (according to TEF3 top management) was useful to be recorded.

Regarding performance:

- Before the standardization of the whiteboard meetings, around 1-hour per day was spent by 10 people in those meetings. By defining a concrete agenda for these meetings, it was concluded that a 15 minutes meeting was enough to categorically approach every relevant subject. An improvement of 0.67 FTE was achieved.
- The concept of problem solving was already present in the team, in form of a weekly meeting. The team meet for 1 hour and half every week, debating open points in the problem solving sheet. Although, similarly to the whiteboard meeting, this process was not standardized, lacking a meeting agenda. An improvement of 0.27 FTE was achieved.

Regarding skills:

- After implementing the whiteboard, it became clear what was bottleneck area activity: CAD Project, CAM Programing and CNC support. This was accomplished not by a thorough analysis, but simply by analyzing the parking lot of the whiteboard: it was the one with more reference *post its*. By doing this analysis, it is possible to know where to focus the team regarding necessity, and more importantly also where to invest in trainings.

- Any team must be able to deliver, regardless of the people present in it. Therefore, to decentralize knowledge, some technicians received training in some managements tasks, to replace the team leader during night shifts, holidays or vacations.

Regarding behavior:

- One of the main distracting factors present were the interruptions by the other TEF3 teams (to use equipment of the TEF3.4 or to know the status of an order request). These interruptions create a small time interval for the interrupted collaborator to return to the focus he was before the interruption. By creating daily service windows of 1-hour where all the customers may go to the area to discuss specification regarding any of the orders, or to use any equipment present in area, it allowed the rest of the team to maintain their focus during the rest of the day.
- The tools manufactured in the CNC were correctly stored, and when one must be used, sometime were spent looking for it. By implementing 5S tools across these storage area, mainly identifying each tool, removing unnecessary ones and optimizing the existing space, the searching time was reduced.

The critical aspect of this phase was related to introduce lean fundamental blocks to employees, and to create a sustainable and interactive culture, giving the 1st step towards excellence. Because being excellent or even making every day better than the previous day is a never-ending road, maturity of lean elements was assessed. This assessment allowed for the understanding of the maturity level of each manager, regarding lean fundamental blocks, creating awareness about level of implementation of lean methodologies and concepts (see Fig. 26).

Figure 26 - PDDIS Framework: Maturity of lean elements (Implementation Phase)

To better understand what were the results of lean implementation in the TEF3.4 Team and its impact on efficiency (see Fig. 27).

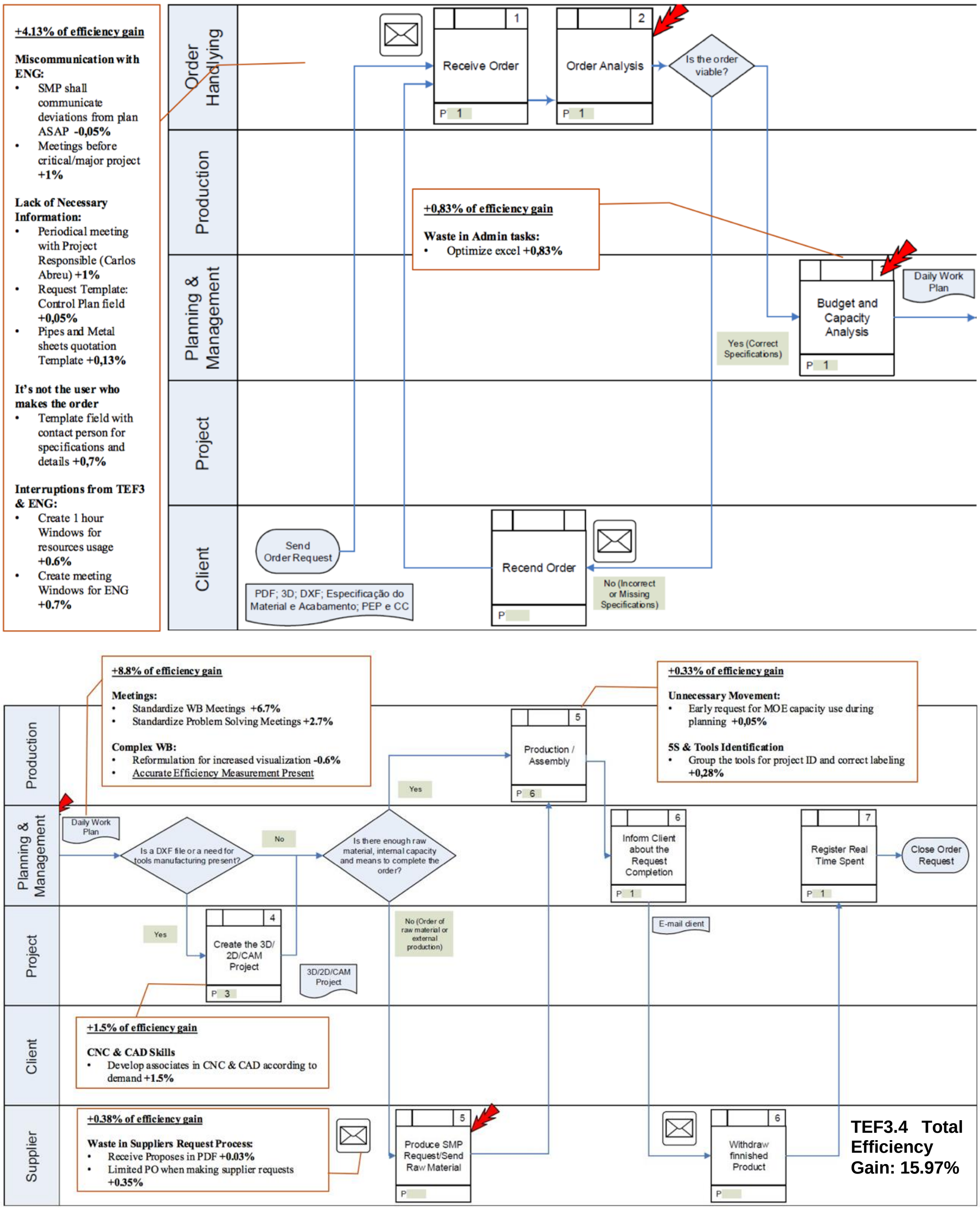


Figure 27 - PDDIS Framework: Efficiency Gains

Top management normally focuses on numbers and efficiency gains, but one important factor should not be forgotten: employees' level of satisfaction. To assess employees' satisfaction, a survey was performed and the results compared with the survey done at the end of the diagnosis phase (presented in Fig. 28).

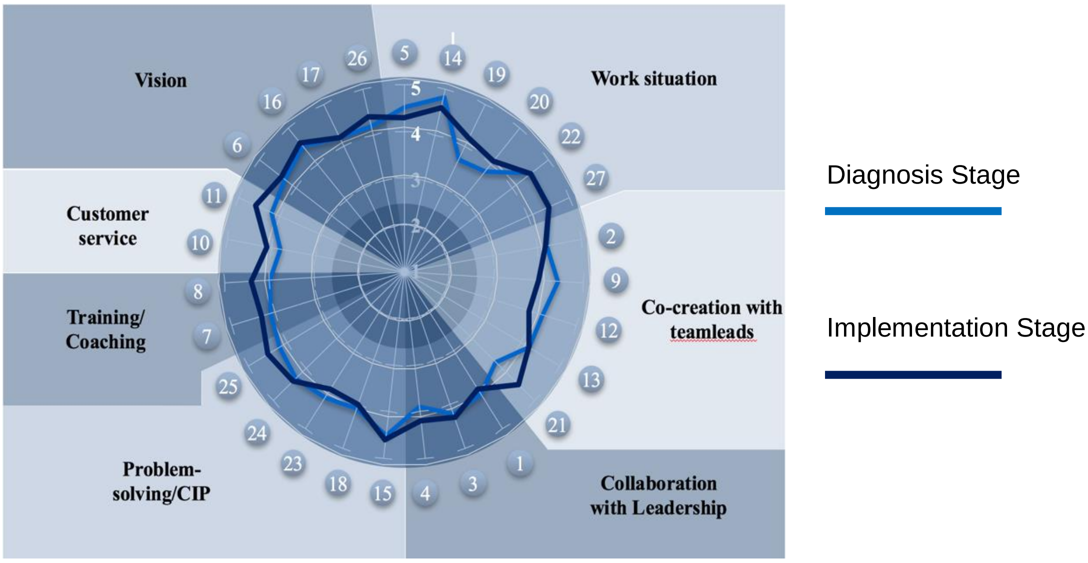


Figure 28 - Employee Survey

Increasing employee satisfaction contributes actively to achieving higher rates of performance and commitment towards lean transformation. Observing both survey results, employees show a high level in all categories (Vision, Customer Service, Training/Coaching, Problem Solving, Collaboration with Leadership, Co-creation with team leads and work situation), especially in Training/Coaching, Customer service and in Vision. The survey showed an increase in high commitment to growth and the development of the site, vision for the future and customer service. These results made the difficulties faced during the Lean Management project clear, with much space for improvements.

Implementation ended the participation of researchers support and their active presence on site, giving managers the opportunity to act autonomously. To clearly state to all stakeholders the end of the researchers' action, a final meeting to present results to employees was organized, clarifying existing doubts and making a final balance of the project.

4.2.5. Stage 5: Sustainability

After completing the first cycle, the TEF3.4 team started a new one, generating new improvement ideas and using this methodology for all product development projects. These activities were often aimed at consolidating the results achieved in the first cycle. Thus, the team leader built a sustainable TIP containing open points from the implementation phase and new improvement ideas or existing problems, making a prioritization, taking into consideration benefits and effort.

When moving to sustainability, it was clear that the improvements achieved were not enough to change the level of performance of the team, regarding lean philosophy and level of standardization. Thus, it was important to increase top management support and commit managers and head of department to lean transformation and the need to keep the pace.

Lean has a high impact on prototype management processes during sustainability, because it ensures a review of all methodologies and tools applied and forces managers and employees to improve continuously to react and adapt to meet customers' needs.

As this project and philosophy is a never-ending story, the team leader, the engineers and the technicians have a fundamental role in maintaining a kaizen culture active and act as role models, by focusing on each lean element, with a determined frequency, according to a sustainability checklist, as shown in table 10 and 11.

Lean Element	**Action**	**Frequency**
One-on-one coaching	Direct report	Monthly
Target & Reports	Follow-up on status of lean management	Weekly
Performance dialogues	Direct reports and follow-up problem solving sessions as required	Weekly
Gemba	Attend on team-leaders meeting	Weekly
Problem Solving	Conduct structured problem solving meetings, where clear actions & next steps are defined and followed-up	Weekly
Communication	Communication about lean management into the organization	Monthly

Table 10 - Team Leader Sustainability checklist

Lean Element	**Action**	**Frequency**
One-on-one coaching	Direct report	Monthly
Target & Reports	Update status of KPIs and set realistic but ambitious targets	Weekly
Performance dialogues	Direct reports and follow-up problem solving sessions as required	Weekly
Gemba	Attend on team-leaders meeting	Weekly
Problem Solving	Conduct structured problem solving meetings, where clear actions & next steps are defined and followed-up	Weekly
Communication	Communication about lean management into the organization	Monthly

Table 11 - Group Leader and Head of Department Sustainability checklist

4.3. Deductions

This thesis provides a guide for implementing Lean thinking in prototype production management processes, within manufacturing companies, by suggesting an organization and a process, based on the evidence from the implementation in a real case, through a practice based practice. This study is highly relevant for both research and practice, since on the one hand it provides elements to build a new framework on an under-investigated subject, i.e. Lean Prototype Management, while on the other hand it provides results, collected in a manufacturing company.

The suggested framework was derived from the literature, as a response to customers' demands of value creation, incorporating sustainability and customization.

In taking into consideration lean management models proposed in literature, it is possible to identify significant differences: the PDDIS framework represents a practice based program to enable companies to coordinate both lean and production management of nonstandard processes in day to day activities; it is constituted by five phases: Preparation, Diagnosis, Design, Implementation and Sustainability (iteration of the process). However, it is also possible to find some similarities, concerning literature framework principles: Kaizen, Standardization, Visualization, Flow and Pull, Zero-Defects, Employees and Leadership and Frontloading, reflected in the PDDIS framework dimensions: Customer, Efficiency and Effectiveness of Processes, Performance Management, Organization and Skills, and Behaviors and Mind-sets.

The voice of the customer is central to any Lean Management system, and it is fundamental to understand the motivating effects of a clear and common understanding of customer needs by the whole Prototype Production team. The Action Research process adopted has been very directive and structured, to allow the initiating of the PDDIS framework in a context that was new to the approach and also, in part, to the focal company. Another important result is the relevance of organizational issues, in particular the people involved. The selection of a collaborative and committed learning network seems to be critical for the successful implementation of Lean PM systems, but after the process is started it could be extended to other company departments.

Another relevant topic is the importance of having some maturity in lean culture. Although, lean has been applied for many years in manufacturing activities in the focal company, engineers were very reluctant and didn't believe in the project and its impact on production management activities, which created some initial barriers.

The truth is that not all companies succeed in implementing lean, because they have a wrong approach, considering indirect areas as being similar to manufacturing processes, highly repetitive and easily standardized. One of the concerns companies must have about applying the "lean" methodology is the impact on engineers. Engineers are not like workers on the shop floor. They are educated, well paid, and expect to have autonomy and be creative in their work. A common image of a lean shop floor can be quite negative. Imagine engineers in their natural work environment being pressured to follow standard procedures for everything they do and constantly pull minutes of non-value added activity out of the process leading to more intense and tightly controlled work for all hours of the day and night. It is no wonder we often see resistance from these professionals when the concept of lean is discussed.

The challenge of this thesis was exactly to show how Lean could surpass these barriers and demonstrate its success and impact on production management processes. To make this happen, people represent a critical asset to boost continuous improvement.

Once a Lean Management project starts and teams are selected, the adoption of lean requires the identification of open-minded employees, the right people to undertake the improvement activities. These people are the key of lean transformation success, as normally there is a high share of employees who do not want to go into a continuous improvement transformation, due to different reasons:

i) Some employees have been working in the company doing the same thing for many years and they are skeptical of the success of new practices (mind-set);
ii) Fear of losing their job;
iii) Complaints about lack of time;
iv) Fear of failing;
v) Difficulty in identifying improvement actions;
vi) Lack of power to implement new actions (top management lack of support);
vii) How lean fits with innovation;
viii) Difficulties to commit with targets and efficiency gains.

There is a need for managers to act as role models and identify possible lean catalyzers, able to identify priorities and problems, people with technical knowledge, committed with a culture that is favorable to change and able to influence others.

During the project, the motivation goes up and down, but one thing must never change, the commitment and the will to change for the better. All entities must believe that this change will be beneficial for the company's success. To preserve and enhance communication between managers and top management, regular meetings were organized at the end of each phase, in order to update top managers about project results, efficiency gains, commitment with improvement actions and share success stories.

In the TEF3.4 team, it was not easy to create a kaizen culture, because there was a barrier concerning lean practices and whether they were able to really impact the core business of the company, taking in consideration the need to adapt to new and unique order requests, in a nonstandard production environment. Thus, many were the doubts about the success of lean adoption, but at the end of the project it was possible to see the real impact of lean in the time process, management commitment and support to employees and communication within the department (between teams), among the departments and with the top management (Table 11).

Participant	Comment
Team Leader	I never thought so much could be achieved by eliminating such small unnecessary tasks. We were used to less order requests, and even had some time gaps. In those gaps we started to document everything, just in case. Back then it was possible, due to the amount of order requests received, but with the growth of the ENG Department, we have more clients than ever before, more orders to work with. With that growth, we couldn't keep up with the level of documentation, or at least with the standard present. But we were so used to the way we worked, it has been always like that. I thought the solution to deal with this increase in demand was to hire someone to aid in the management of the area. But now, with the same resources, the same people, and working not harder but smarted, we can now achieve even more.
Production Engineer	Lean manufacturing was something I was already aware of. And I knew it was something very hard to implement in an area which receives nonstandard production order – the purpose of it was to be able to deal with nonstandard production. But I never thought so much could be achieved in the management area of a production team. The simple flow and reflow of information we had, had some improvements to be implemented. But when someone works so many years with the same system, it becomes harder and harder to see these improvement actions. Everything seems ok and cannot be done in a different way. With this new processes not only an improvement was achieved, but the mind set for continuous improvement was developed in the team.
Technician	I didn't believe in this new system until I've tried. It seemed easier when I had an order to perform, and had to take it from start to finish. I was already used to ask the engineers what I was supposed to deliver. Now I can see the time frame of an order though references and tasks to be performed, what operation areas need more support, and why things are done the way they are. Now my team leader has time for coaching sessions and structured teams' problem solving.

Table 12 - PDDIS framework impact: participants' feedback

The reason behind Lean Management application failure stands the managers and employees' inability to continue performing according to lean methodologies, according to a kaizen culture, involving everyone in a common-sense, low-cost approach applied in the prototype management process, in order to standardize processes, skills and design methods, the lack of support and commitment from top managers, and the non-immediate impact on the efficiency of the product development processes.

So, the PDDIS framework was important, because it focuses on a practice based approach, instead of focusing on improving the process, which means, it helped to standardize general management processes in the TEF3.4 team, have a better activities calendar and plan, and a quicker follow-up of implemented actions. Right from the diagnosis phase, it was clear that an increase of transparency would be the basis for efficiency gains. Daily routines and problems causing inefficiencies were not discussed in a systematic way and best practices were not shared as standards. With the integration of an agenda with deliverables in whiteboard meetings, the efficiency of the meeting was drastically increase – "Already?" was a common response in the first couple of weeks from some members of the team. During these meetings, the previous day is revised and problems with impact on efficiency are identified, and these are the background for future improvements. If they are not immediately solved, they need to be discussed in detail, through problem solving sessions. Also with regular sit-ins, which means, daily process observation of an engineer or manager by a colleague. With this tool, best practices can be defined, as well as the identification of improvement points in each process.

To end this chapter, it is important to highlight the importance of Top Management support during a Lean Management framework application. Top managers have a fundamental role in maintaining this culture alive, by participating actively in whiteboard meetings, aligning with managers frequently to assess maturity of lean elements, as well as having a clear overview about the current state, success stories and existing problems, motivating team members to perform better, which translates to a better task specification of each reference and therefore each order, guarantying an higher quality prototype to be tested, aiding the ENG department on creating highly innovative products, available on the market before competitors, increasing the company's market share and success.

As this whole process is a never-ending story, top managers must constantly push team members to improve themselves, suggesting new ideas and improvement actions, which will enable companies' growth.

5. Conclusions

The increased international competition in the current open global market is putting pressure on companies to improve their performance frameworks. As seen, Lean Management is an emerging topic and has been introduced as a concept which is able to improve the managerial processes, by applying lean thinking to the indirect areas, which have a significant impact on the companies' value chain. Currently, most organizations deeply depend on their capacity to achieve more, using less. This translates in the necessity of companies to undergo a lean transformation, which will have a clear impact on the quality, cost and delivery of products.

The reason behind most companies' failure to try to implement lean is simple: Companies see lean as an opportunity to achieve competitive advantage but disregard the fact that the Lean philosophy is a never-ending story, set in a sustainable organizational culture of the pursuit of excellence. First of all, companies need to focus on building a strong kaizen culture, supported by a knowledge-based environment, a Chief engineer (entrepreneurial) technical leadership, a Value-focused planning and development, and finally a focus on creating a flexible, adaptable and highly responsive product development process. If companies do not have an organizational culture, based on strong continuous improvement values, implementing changes will be impossible. People are the core asset of an organization and are fundamental in the success of lean transformation.

The focus of this thesis is to understand how companies can implement a lean management framework in prototyping, nonstandard production areas, one that is able to impact the efficiency of product development processes. Taking into consideration the AR process and consequent application of PDDIS framework in the TEF3.4 team, it is possible to conclude that Lean Management is fundamental to boost performance and growth, through a continuous improvement culture and high focus on value creation, based on daily capacity management, transparency and visualization.

To understand the real impact on TEF3.4 team, it is important to establish the initial state. Initially the team didn't have a fluid flow of information and were not collaborative, and also had a low level of standardized processes. Thus, they felt the need for guidelines to help improve the resolution of problems and avoid wastes, such as: time waiting for information, reflow of information, high share of time spent at meetings and producing too many reports. Additionally, engineers didn't believe in the Lean Management project, concerning the indirect areas thus creating several barriers.

PDDIS framework implementation enabled the TEF3.4 team to build an organizational culture of continuous improvement, to identify improvement points and solve problems in a sustainable way, to level daily capacities between employees, to optimize processes, eliminating non-value tasks, and finally, to share knowledge and best practices within the department. As PDDIS framework is a continuous improvement cycle, managers must assess the department's current state, by answering to the following questions:

- Are the changes leading to new standardized processes that are the basis for further waste reduction?
- Are people throughout the organization engaged in continuous improvement and aligned around a common set of objectives?
- Are all the soft tools and harder technologies being used to support people improving the delivery of products and services to customers?

The essence of lean application lies exactly in the continuous challenge of being better and working towards perfection and customer satisfaction. The problem is lean must be applied by everyone, every day, everywhere, and without a set deadline.

Lean Prototype Production Management is takes an important role in aiding the R&D to produce faster, high quality and low-cost products, as it provides a significant contribution to fixed cost reduction and implements a new standard for sustainable continuous improvement in indirect areas.

To conclude, Lean management at the focal company had some problems regarding standardization of processes, as the TEF3.4 team was characterized by non-repetitive production processes: A team which must be able to deal with any kind of production order, new designs, new technologies, derived from the R&D. Despite this, the PDDIS framework was able to achieve a high share of efficiency gains, in total 16 %, representing the impact of the lean frameworks in the indirect areas.

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7. Appendices

Appendix I – Employee Survey

Questão	Concordo plenamente	Concordo parcialmente	Não concordo nem discordo	Discordo	Discordo completamente	N/A
1. O meu departamento tem uma equipa de gestão* forte e motivadora	☐	☐	☐	☐	☐	☐
2. A minha chefia direta tem um claro entendimento dos desafios nas minhas tarefas diárias e suporta-me na resolução de problemas	☐	☐	☐	☐	☐	☐
3. Sou respeitado e reconhecido pela minha equipa de gestão*	☐	☐	☐	☐	☐	☐
4. A nossa equipa de gestão* é um exemplo a seguir no meu local de trabalho	☐	☐	☐	☐	☐	☐
5. Trabalhamos de forma eficiente e como uma equipa diariamente	☐	☐	☐	☐	☐	☐
6. A nossa equipa de gestão* está focada no sucesso da Bosch TT	☐	☐	☐	☐	☐	☐
7. A minha chefia direta reserva tempo suficiente para o meu coaching e para planear o meu desenvolvimento	☐	☐	☐	☐	☐	☐
8. Recebi formação suficiente para o desenvolvimento das competências necessarias ao desempenho das minhas tarefas.	☐	☐	☐	☐	☐	☐
9. A minha chefia direta tem confiança em mim no bom desempenho das minhas tarefas	☐	☐	☐	☐	☐	☐
10. Tenho todo o material e documentação necessária para prestar um bom serviço ao cliente interno e externo.	☐	☐	☐	☐	☐	☐
11. Preencho todos os pré-requisitos técnicos para poder prestar um bom serviço ao cliente interno e externo.	☐	☐	☐	☐	☐	☐
12. A minha chefia direta mantém-me informado de todos os assuntos relevantes às minhas tarefas	☐	☐	☐	☐	☐	☐
13. A minha chefia direta está disponível para perguntas e respostas de uma forma pronta e competente	☐	☐	☐	☐	☐	☐
14. Gosto de ir para o trabalho	☐	☐	☐	☐	☐	☐
15. Sou encorajado a contribuir com as minhas ideias e a continuamente melhorar os nossos métodos de trabalho	☐	☐	☐	☐	☐	☐
16. Sinto-me comprometido com o crescimento e desenvolvimento da nossa fábrica/localização	☐	☐	☐	☐	☐	☐
17. Existe uma visão para o futuro da nossa equipa na qual me posso guiar	☐	☐	☐	☐	☐	☐
18. As reuniões regulares de performance com a minha chefia direta identificam os potenciais de melhoria corretos assim como as corretas ações de melhoria correspondentes	☐	☐	☐	☐	☐	☐
19. A minha performance é medida tendo em conta diversos indicadores	☐	☐	☐	☐	☐	☐
20. Diretivas e procedimentos são implementados de uma forma consistente em todas as áreas do nosso dept.	☐	☐	☐	☐	☐	☐
21. Eu recebo o adequado reconhecimento do meu team leader quando desempenho bem o meu trabalho	☐	☐	☐	☐	☐	☐
22. Tenho a independência suficiente para bem desempenhar as minhas tarefas	☐	☐	☐	☐	☐	☐
23. Temos informação suficiente para perceber e resolver problemas	☐	☐	☐	☐	☐	☐
24. Procuro potenciais de melhoria de uma forma proactiva	☐	☐	☐	☐	☐	☐
25. Fiz mudanças no meu local de trabalho das quais me orgulho	☐	☐	☐	☐	☐	☐
26. A visão de longo-prazo do meu departamento motiva-me	☐	☐	☐	☐	☐	☐
27. A minha fábrica/localização tem uma boa performance	☐	☐	☐	☐	☐	☐

Appendix II – Maturity Assessment Template

Observations	0 ⇨ Level 1 ⇨	Level 2 ⇨	Level 3 ⇨	Level 4 ⇨	Level 5 ⇨
A. Daily whiteboard meetings	☐Whiteboard with all mandatory content established ☐All elements covered in meeting ☐Timing is respected	☐Level 1 fulfilled ☐Connection between different whiteboard elements is understood ☐Purpose can be explained	☐Level 2 fulfilled ☐Balanced talking / listening ☐Associates are involved in bringing up problems on a regular basis	☐Level 3 fulfilled ☐Involve associates in systematically identifying issues whenever there are gaps on KPIs and sharing best practices	☐Level 4 fulfilled ☐Whiteboard meetings are leading to actions for coaching of associates ☐Regular review of whiteboard and benchmarking with others
B. Best practices	☐Associates are aware of purpose of best practices and routine of best practice sharing is defined ☐>3 best practices related to core tasks under development	☐Level 1 fulfilled ☐>3 best practices related to core tasks tested and approved by managers	☐Level 2 fulfilled ☐>3 best practices related to core tasks adequately documented and used systematically ☐Further (small) best practices shared	☐Level 3 fulfilled ☐Entire team involved, best practices continuously updated / adapted ☐Best practices for tasks covering 50% of the department's time	☐Level 4 fulfilled ☐Best practices for tasks covering 80% of the department's time ☐Best practices revised at least every 6 months (enforced)
C. Sit-ins	☐Objectives of Sit-ins are clear to managers and associates ☐First Sit-ins have been done with all associates	☐Level 1 fulfilled ☐Sit-ins are prepared upfront (e.g. what to observe) ☐Sit-ins are used to verify adherence to best practices	☐Level 2 fulfilled ☐Sit-ins are done in adequate frequency, planned ahead and not skipped / shortened on short notice	☐Level 3 fulfilled ☐Issues identified in Sit-ins are leading to problem solving ☐Best practices identified in Sit-ins documented and shared with team	☐Level 4 fulfilled ☐Training of new processes / new associates / technical support is clearly differentiated from Sit-ins
D. Coaching sessions	☐Manager is taking a deep dive on how associates are feeling and root causes	☐Level 1 fulfilled ☐Manager asks open questions ☐Coaching sessions are action oriented and manager is responsive	☐Level 2 fulfilled ☐Sessions scheduled in appropriate frequency with each associate ☐Manager balances talking / listening, involves staff, shows empathy	☐Level 3 fulfilled ☐Formalized personal development plan (e.g. coaching log) owned by associate ☐Coaching sessions build on trustful relationship, sharing of feelings	☐Level 4 fulfilled ☐PDPs in line / linked to future state skill matrix
E. Performance dialogs (structured performance review with next higher hierarchy level)	☐Covering all KPIs, productivity and non-productivity ☐Discussion of deviations	☐Level 1 fulfilled ☐Meeting prepared and meeting agenda clearly defined ☐Timing is respected	☐Level 2 fulfilled ☐Dialogs are structured and leading to adequate problem solving sessions and update of TIP	☐Level 3 fulfilled ☐Balanced talking / listening ☐Involving associates, escalations from teams and teams' solutions	☐Level 4 fulfilled ☐Timely sharing of information, clear split between short-, medium- and long-term issues
F. Problem Solving and weekly team meetings	☐Problem solving sessions are being scheduled as a routine ☐Team is coming up with clear problem statements	☐Level 1 fulfilled ☐Problems for specific problem solving session are selected properly	☐Level 2 fulfilled ☐Problems addressed continuously ☐Deep dive on problem root causes (e.g. issue tree used regularly) ☐Problem solving linked to other tools (e.g. TIP) to ensure follow-up	☐Level 3 fulfilled ☐Manager balances doing and delegating and involves associates ☐Team members are coached in problem solving	☐Level 4 fulfilled ☐Problems identified are rapidly solved and solutions implemented ☐Structured PS sessions used on appropriate topics
G. Tactical Implementation Plan (TIP)	☐Purpose of TIP understood	☐Level1 fulfilled ☐Weekly review / discussion of TIP ☐TIP updated on a regular basis by each team	☐Level 2 fulfilled ☐Management reviews TIP regularly ☐TIP used as single plan for all actions of the team	☐Level 3 fulfilled ☐Actions of TIP are being completed according to plan	☐Level 4 fulfilled ☐TIP includes actions to strengthen Continuous Improvement and the team
H. Skills matrix	☐First version of skills matrix established (list of skills with priorities and evaluation of each team member)	☐Level 1 fulfilled ☐Development target is defined for each skill and each team member	☐Level 2 fulfilled ☐Detailed action / training plan to reach development target	☐Level 3 fulfilled ☐Sit-ins are leading to a reflection on necessary updates of Skills Matrix ☐Skills matrix is used as an input for Capacity Mgmt decisions	☐Level 4 fulfilled ☐Skills matrix is used to drive capacity management between teams and also revised with respect to strategy of area
I. Capacity management	☐Daily capacity is visualized and reviewed during daily check-in ☐Team understands how to evaluate daily capacity	☐Level 1 fulfilled ☐Daily tasks are prioritized in check-in based on available capacity and re-allocated where possible	☐Level 2 fulfilled ☐Issues identified in daily capacity mgmt leading to problem solving ☐Mid-/long-tem capacity mgmt tool is existing (can be simple tool)	☐Level 3 fulfilled ☐Mid-/long-term capacity reviewed regularly and mid-/long-term tasks planned accordingly ☐Capacity mgmt improved continuously	☐Level 4 fulfilled ☐Capacity mgmt linked with other elements (skill development, future organization, strategy of the area)